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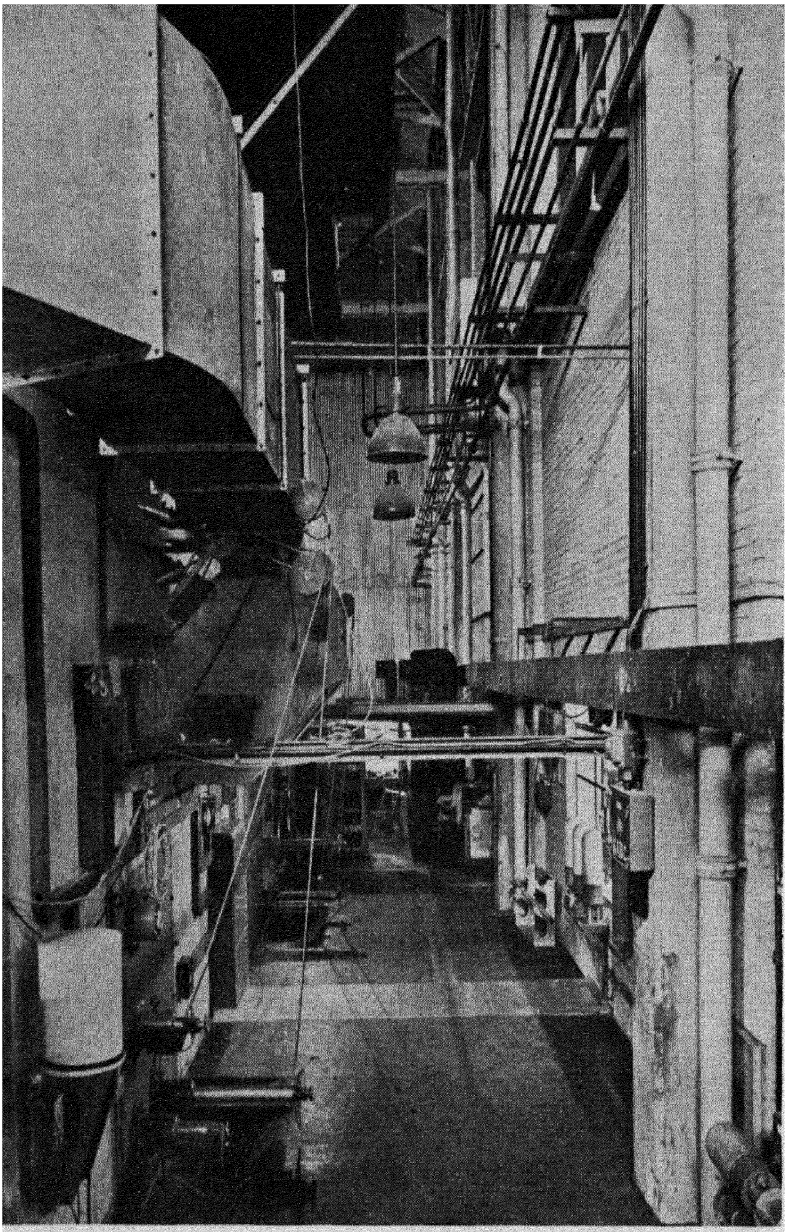
ATOMIC ENERGY YEAR BOOK



[*Photo by permission of H.M.S.O.*

GLEEP. The "control" face is on the left. In the bottom corner can be seen the chambers containing boron trifluoride gas which are used to measure the intensity of neutrons in the pile, and hence to control the power level at which the pile is operated.

ATOMIC ENERGY YEAR BOOK

Edited by

JOHN TUTIN, D.Sc.

TEMPLE PRESS LIMITED
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CONTENTS—*continued*

A STATEMENT ON ATOMIC ENERGY*

by

The Right Honourable WINSTON S. CHURCHILL

By the year 1939 *it had become recognized among scientists of many nations that the release of energy by atomic fission was a possibility. The problems which remained to be solved before this possibility could be turned into practical achievement were, however, manifold and immense. Nevertheless, the potentialities of the project were so great that His Majesty's Government thought it right that research should be carried on in spite of the many competing claims on our scientific manpower.*

At the same time, under the general arrangements then in force for the pooling of scientific information, there was a full interchange of ideas between the scientists carrying out this work in the United Kingdom and those in the United States and Canada.

The whole burden, including the setting-up of the plants and many technical processes connected therewith in the practical sphere, constitutes one of the greatest triumphs of human genius of which there is record.

This revelation of the secrets of Nature, long mercifully withheld from man, should arouse the most solemn reflections in the mind and conscience of every human being capable of comprehension. We must indeed pray that these awful agencies will be made to conduce to peace among the nations, and that instead of wreaking measureless havoc upon the entire globe, they may become a perennial fountain of world prosperity.

* Issued in a White Paper, published by H.M.S.O., August, 1945

PREFACE

LESS than seven years have passed since the engineer in charge moved the control rod which started up the first atomic energy reactor. The date was December 2, 1942, a date which will eventually become recognized as one of the most important in the history of civilization. At present its significance is not fully appreciated: most people are more deeply preoccupied with the survival of civilization as we know it rather than with the fact that we are indeed on the threshold of a new era. Not only have we a new source of power of almost unlimited possibilities, but also atomic by-products of such importance in all fields of scientific research that even if atomic energy were never harnessed for industry, the discovery and applications of its by-products would still remain one of the most significant events in world progress.

Assuming that scientists, engineers, chemists and metallurgists are allowed to proceed with the development of atomic energy, it is certain that in due course atomic energy power units will become available for commercial purposes. Already, since December 2, 1942, there are a number of live reactors operating in the U.S.A., Canada, Great Britain and, probably, in the U.S.S.R. Indeed, expenditure on atomic energy in terms of human effort and finance has been on such a scale that the development of this new source of power has enjoyed an unprecedented acceleration and momentum.

One must not be unduly or unreasonably impatient. The pace of advance is still incredibly swift compared with the leisurely development of steam and electricity in the last century. There are some important technical problems which at present are at the stage of partial solution only, and atomic energy cannot emerge as a world industrial factor until these problems are completely solved.

For this reason, every major industrial nation must be ready to share in the efforts, responsibilities and rewards which will flow from the commercial development of atomic energy. This calls for the closest possible integration of industry and science, and especially of a keen awareness, on both sides, of mutual interests, problems and achievements.

The present volume is intended to assist in this essential integration, and particularly to provide a convenient means whereby the industrialist and technician may have at hand

reasonably up-to-date information on the development of atomic energy. For this, an expert knowledge of nuclear science is not essential, but this book will fail in its purpose if it does not encourage a wider interest in and familiarity with current progress in a field of science of such profound importance.

Already by-products in the form of radio-isotopes are in action in research laboratories throughout the world, and employed mainly against highly resistant problems in that vast "no-man's land" which lies between knowledge and ignorance. As even the immediate consequences are unpredictable, we will not attempt to assess the ultimate results.

THE EDITOR.

CHAPTER I

HISTORY OF NUCLEAR SCIENCE

CLASSICAL ideas on the nature and properties of matter culminated in the atomic theory of the 19th century. It was accepted that all matter was made up of discrete, indestructible particles or atoms, which were classified into 92 different species or elements. From the atoms of one or more of these elements all the different chemical compounds that exist in Nature are built up. But it was regarded as a cardinal point that the atoms of any one element could in no way be changed or converted into those of another.

The fundamental break with this theory occurred when the French physicist H. Becquerel, in 1896, discovered that one of the elements—uranium—was continuously emitting radiation of an unknown type which could penetrate matter and affected a photographic plate. Further study of this new-found property of uranium led to the isolation of another element—radium—from the uranium deposits in Joachimstal by Pierre and Marie Curie in 1898. Radium showed, to a much greater degree, this same property of emitting radiation and it was clear that the phenomenon of "radio-activity," as it was called, was altogether different from those associated with normal chemical reactions between atoms. In 1902 Rutherford and Soddy, who were then working at McGill University, Montreal, suggested that it could only be explained by the assumption that the atoms of uranium, radium and other radio-active elements, which had by then been discovered, were unstable and were continuously breaking up at rates which were characteristic for each element.

This suggestion was conclusively proved by detailed experimental work in the course of which the nature and properties of the radiation from radio-active elements were discovered. Part of this radiation, the so-called "alpha-rays," consists of helium atoms, carrying a positive charge of electricity, and these were found to be of the greatest value as a tool for further exploration of the structure of atoms.

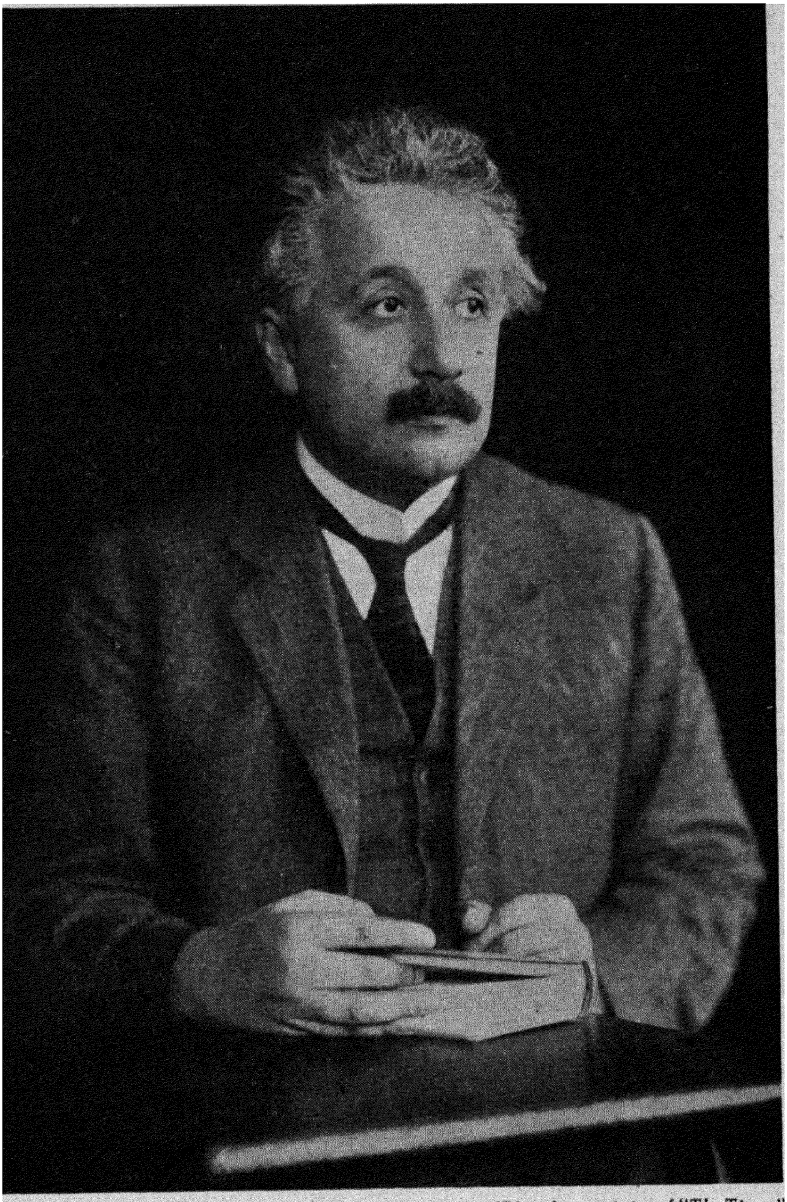
It was, in fact, research on the penetration of matter by "alpha-rays" which led Rutherford, at Manchester University in 1911, to the fundamental discovery that the whole mass of each atom was concentrated in a minute central nucleus which carried a positive electric charge.

Round this nucleus, but at relatively very great distances, revolved elementary negative electric charges — the " electrons "—in numbers sufficient to neutralize exactly the positive charge of the nucleus. The mass of these electrons was negligible compared with that of the nucleus. In terms of classical electro-magnetic theory, however, such a system would be unstable and the energy of the revolving electrons would, in a very short time, be lost as radiation. Niels Bohr, of Copenhagen, put forward a theory in 1913 which combined Rutherford's model of the " nuclear atom " with the quantum theory of energy which had been enunciated by Planck, to explain limitations of the classical electro-magnetic theory.

The resulting Rutherford-Bohr model of the atom proved to be of the greatest value in explaining the results of experimental work in every branch of physics and, in particular, the relationship between the different elements as regards their ordinary physical and chemical properties. These are determined entirely by the electrons revolving round the nucleus and are, therefore, practically independent of the mass of the nucleus. It was, therefore, immediately understood that any element, with a given charge on the nucleus, could exist in more than one modification with different atomic masses but almost identical physical and chemical properties.

The existence of such modifications of any element, which were known as " isotopes," had first been suggested by Soddy in 1910 as a result of studies of the decay products of the natural radio-active elements. Aston, at Cambridge, followed up work, which had been started by J. J. Thomson and developed the so-called " mass-spectrograph " which subjected a stream of electrically charged atoms—or ions—to a crossed electric and magnetic field and brought those of different mass to a focus at different points. It was proved, with the help of this instrument, that the great majority of elements consisted of a mixture of two or more isotopes and that the relative weight of the atom of any given isotope of any element was very nearly a simple multiple of the weight of a hydrogen nucleus, or proton.

Because the isotopes of an element have almost identical chemical properties it is in general extremely difficult to separate them or even to change appreciably their relative concentration. We must take recourse to processes which depend on the nuclear mass of the atoms, making use of the difference in mass between isotopes. This difference is usually



[*Photo by permission of "The Times."*

Professor Albert Einstein who, in 1905, discovered the fundamental equivalence of mass and energy.

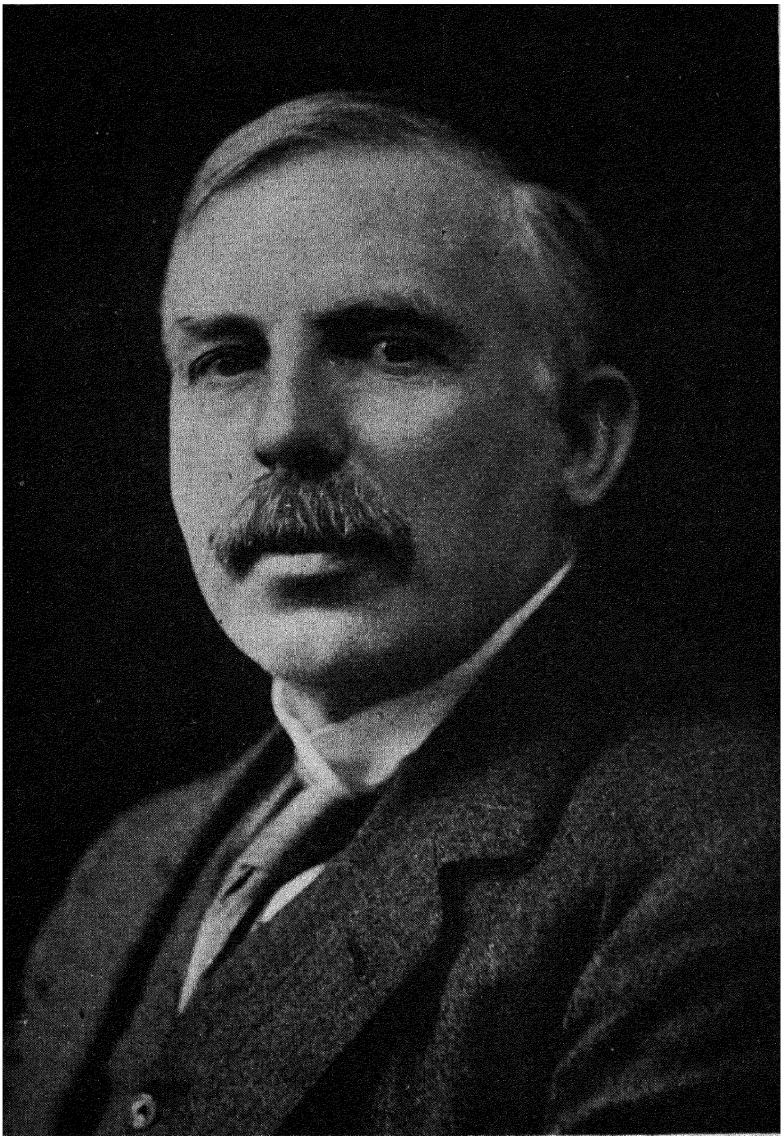
only a small fraction of the total mass. Moreover, while some of these methods, such as that used in the mass-spectrograph, are not difficult to apply, they can ordinarily deal only with very small quantities of material, too small to be of much practical use. In 1932 Urey and Brickwedde, of Columbia University, New York, showed that hydrogen itself is not a simple element but contains a small amount (about 1/5000) of an isotope known as "heavy hydrogen" or deuterium which has almost double the mass of a proton. Because, in this case, the ratio of the masses of the isotopes is as two to one the physical and chemical properties of hydrogen and deuterium are sensibly different and it was found possible to separate them, in a pure state, in large amounts by normal technical methods.

The atoms of nearly all the elements are stable and it is only in the case of the radio-active elements that spontaneous disintegration of the nucleus takes place. Although it was known that, when this occurred, energy was released, atom for atom, on a scale incomparably greater than that connected with any known chemical reaction, it was recognized to be of no practical use because the rate of decay can in no way be influenced and it was obvious that any hope of understanding the conditions which might make such influence possible would depend on an understanding of the structure of the atomic nucleus.

The first decisive step in the solution of this problem was taken by Rutherford who, in 1919, showed experimentally that the charged alpha particles from radium -C could, in rare instances, collide with the nucleus of an atom of the common element nitrogen in such a way that it broke up and, as a result of the collision, the nuclei of two other atomic species or elements (oxygen and hydrogen) were formed.

While the discovery of radio-activity had shown that some of the elements could, spontaneously, break up to form other elements, Rutherford had now shown that the particles emitted in this process could be used to break up, or transmute, the atoms of other elements which were normally stable.

This development was pursued in the following years by Rutherford and Chadwick, who found that many other light elements could be transmuted in a similar way. In each case a proton was ejected, and generally the process of transmutation was accompanied by the release of a considerable



[*Photo by Walter Stoneman.*

Lord Rutherford who, in 1910, discovered the nucleus and identified its fundamental features.

amount of energy. It thus appeared that the proton was a common constitution of atomic nuclei and one of the fundamental particles of which matter is built up. Moreover, the release of energy in these processes was a further indication of the store of energy resident in atomic nuclei.

In parallel with this development, Rutherford, with Chadwick and other colleagues and students of the Cavendish Laboratory at Cambridge, attacked many other questions concerning the properties of atomic nuclei and their structure, laying the experimental foundations of a whole new branch of physics, now known as nuclear physics, arising from Rutherford's discoveries, first of the nature of the phenomenon of natural radioactivity; secondly, of the existence of the atomic nucleus; and thirdly, that some nuclei could be transmuted by bombardment with alpha particles.

A further very important step was taken in 1932 when Cockcroft and Walton carried out an experiment in which hydrogen nuclei, produced artificially in an electric discharge and accelerated to a high velocity by means of an applied voltage, were used to bombard another stable element, lithium. The atoms of this element were found to disintegrate, and transmutation, the dream of the alchemists, had been achieved in a completely controlled laboratory experiment.

In this transmutation, and in others which followed this new discovery, the release of energy was enormous for such a minute event as a reaction involving a single nucleus. Nevertheless, the number of nuclear reactions was so small that the amount of energy generated by the reaction was extremely small compared with the total input of energy used to produce the bombarding particles. The practical value of these nuclear reactions as a source of energy was still completely negligible.

The reason is not far to seek; not only are these nuclear reactions very rare events, but the reactions are not self-propagating. This is quite different from the chemical reactions with which we are familiar in our daily life, such as the combustion of coal or oil. Once started, these propagate themselves and the reactions develop and spread, involving the whole bulk of material: thus the lighting of a fire releases enough heat to ignite the neighbouring fuel, which in turn releases more heat to ignite more fuel, and so on. This is not the case for the nuclear reactions which have so far been mentioned; the particles which are formed in them

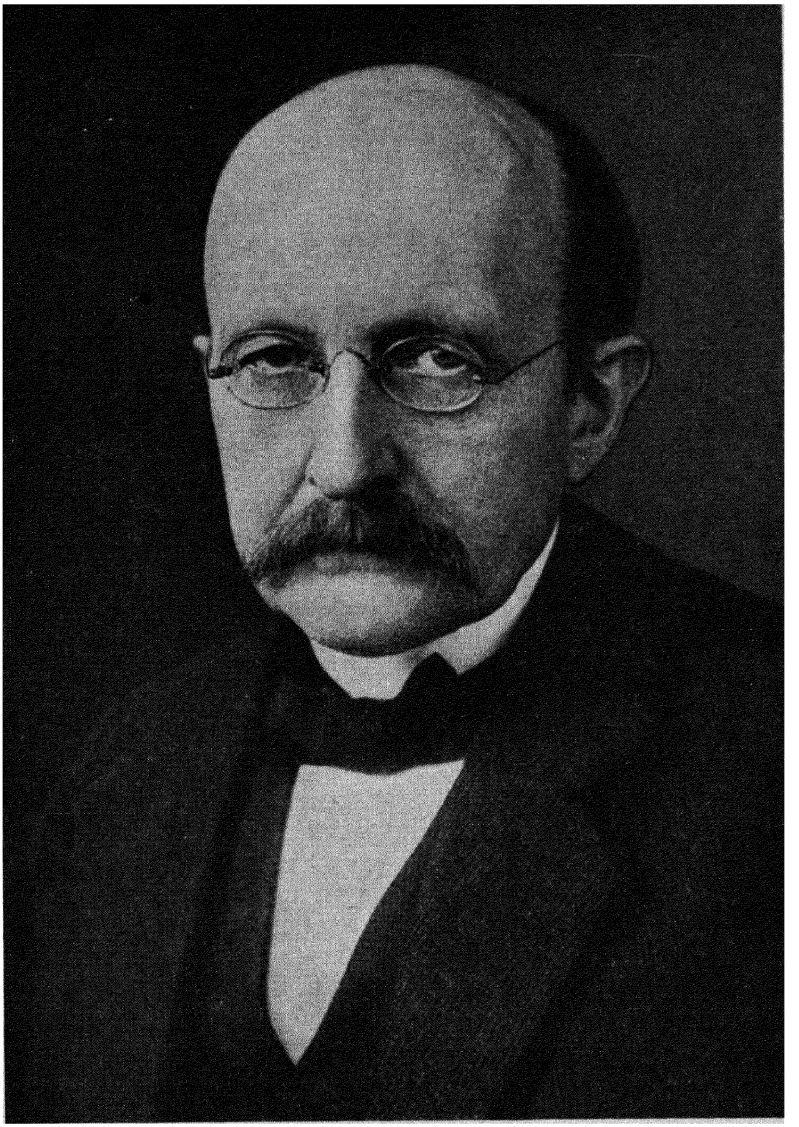


Photo by permission of "The Times."

Professor Max Planck, who, in 1900, discovered the quantum law which is the foundation of modern physics.

are insufficient to affect neighbouring nuclei so as to maintain the reaction and propagate it. It is clear that if we wish to tap the hidden reserves of energy in atomic nuclei and put them to practical use we must find a reaction which can propagate itself; for example, a reaction in which particles are emitted of the same kind that initiated it and in sufficient numbers to affect neighbouring nuclei, which in their turn emit new particles to react with other nuclei, thus beginning a chain-reaction which spreads through the whole mass.

It is convenient at this point to consider the form of this reserve of energy in atomic nuclei. As long ago as 1905 Einstein showed that, according to the theory of relativity, there is no essential difference between mass and energy, but that energy has mass and mass represents energy. For many years the proof that energy and mass were equivalent depended on indirect, although conclusive, evidence. The reason for lack of this immediate evidence is the extreme size of the ratio between mass and energy. A very small mass corresponds to a very large amount of energy. For example, a mass of one ounce transformed entirely into heat energy would be sufficient to convert nearly a million tons of water into steam. The fantastic size of the figure for conversion of mass to energy explains why a loss of mass has never been observed in ordinary chemical processes; the heat given off in combustion has, we believe, mass associated with it, but its amount is so small that it cannot be detected by the most sensitive balance.

Very striking and direct evidence for the equivalence of mass and energy was furnished by the experiments on the artificial transmutation of atoms. It was shown that in these nuclear reactions a release of energy was always accompanied by a decrease of mass and that the equivalence between mass and energy was exactly as predicted by Einstein. It thus appears that in these nuclear reactions matter is being partially converted into energy and that the reserve of energy of the atomic nucleus is hidden in the most obvious place, its own mass. There is therefore a store of energy resident in matter which is enormously greater than that available to us from any known chemical process. It is clear that since no such extraordinary sources are known on this earth there can be no appreciable conversion of matter into energy. On the other hand, it is now generally accepted that it is this store of energy in matter itself which maintains the heat

of the sun and of other stars, through a cycle of nuclear changes in which matter is converted into energy.

In the newly discovered reactions, involving atomic nuclei rather than the outer screen of electrons, there was an enormous release of energy of this type for each atom that was successfully bombarded. The scientific importance of the results was immense but the apparent practical value was still negligible because only one successful collision could be obtained in many thousands and the total input of energy in producing the bombarding particles was far greater than the energy release from the very few successful collisions.

This low efficiency is, in part, due to the very small size of the nucleus compared with that of the atom as a whole. The massive central nucleus of an atom, with its surrounding cloud of electrons, has often been compared with the sun in the planetary system and a direct collision between the bombarding particle and the nucleus, which would be needed to break up the latter, is an inherently improbable event. But when both the nucleus and the bombarding particle are postively charged there will be a force of repulsion between them which will greatly lessen the chance of a direct collision. Only particles of very high energy can overcome this force and nearly all the bombarding particles will lose their energy in collisions with the electrons surrounding the atomic nuclei before they have a chance of reaching the nucleus itself.

In 1932 Chadwick, working at Cambridge, made a discovery of fundamental importance. The observation was first made by Bothe and Becker, in Germany, that, when the element beryllium was bombarded with the alpha-particles emitted by polonium—a natural radio-active element—a very penetrating radiation was emitted. Joliot and his wife, Irene Curie-Joliot, in Paris, carried these observations further and finally, as a result of detailed measurements of the masses and energies of recoil particles, Chadwick was able to prove that this apparent radiation consisted of fundamental particles which had a mass almost the same as that of a proton, but had no electric charge. These new-found particles were called "neutrons," and it was at once realized that they, together with protons, were likely to be the ultimate constituents of the nuclei of atoms of all elements. The nucleus of any atom could be built up from the number of protons required to give the observed positive electric charge

together with the additional number of neutrons to bring the nuclear mass up to the observed value.

The discovery of the neutron was, however, of even greater practical importance in that its lack of electric charge made it an ideal projectile for carrying out nuclear transformations. The use of neutrons as a means of exploring the structure and reactions of atomic nuclei was taken up vigorously in physics throughout the world. Neutron sources could be made either by mixing radium or polonium with beryllium so as to take advantage of the nuclear reaction already mentioned or by the use of an instrument, known as the "cyclotron," which had been developed by E. O. Lawrence, of the University of California, Berkeley. This instrument has been of very great value in the production of high-energy beams of charged atoms of nuclei and many nuclear reactions, which could be carried out with such beams, were found to produce neutrons.

In the meantime an important contribution to the rapid advance in the new science of nuclear physics was made by Joliot and Mme. Irene Curie-Joliot who, in 1933, showed that certain elements, which are normally stable, undergo nuclear reactions when bombarded by alpha-rays and yield new atomic nuclei which are isotopes of known elements but which are not stable and decay in the way characteristic of the natural radio-active elements. This decay was associated with the emission of "beta-rays" which, since the early work on radio-activity, had been recognized as being negatively charged electrons whose mass is negligible compared with that of either the proton or the neutron. In any radio-active series the emission of an electron, while leaving the atomic mass number unchanged, results in the increase, by one unit, in the net positive charge of the nucleus.

In 1934, E. Fermi, and the school of physicists then working with him at Rome, began an intensive study of the reactions produced when the nuclei of all atomic species were subjected to neutron bombardment. In the course of this work the heaviest known elements were examined and, in particular, uranium—with the atomic number 92—was subjected to neutron bombardment. The results of this work showed that new isotopes were formed which were unstable and were subject to radio-active decay. It therefore seemed that, by bombardment of the heaviest known atom with neutrons, it was possible to produce in the laboratory atoms of higher

atomic number, 93 and upwards, than were found in Nature.

Further experimental work, however, led to certain difficulties in this explanation and it was found to be impossible to account for the existence, in the normal arrangement of atomic species, of the very large number of so-called "trans-uranium" elements that were discovered. At this time it was generally accepted that these new elements were all, in fact, of higher atomic number than uranium and elaborate chemical tests had proved that they certainly could not be identified with any of the elements immediately below uranium in atomic number or weight.

Professor O. Hahn and Dr. Strassmann, of Berlin, became interested in this problem at the end of 1938 and, from the particular point of view of their chemical nature, carefully re-examined the new elements. In January, 1939, they published a most important paper in which they reported positive chemical evidence to show that one, at least, of the new isotopes which were believed to be of higher atomic number and mass than uranium was, in fact, an isotope of the element barium which has an atomic number and mass not very different from half that of uranium.

Immediately afterwards Dr. O. Frisch and Professor Lise Meitner pointed out that this discovery could only mean that, when uranium was bombarded by neutrons, a nuclear reaction took place of a kind utterly different from any so far studied and that the uranium nucleus split into two parts of roughly equal mass. This phenomenon, for which they proposed the name "nuclear fission," could be explained in terms of the theory of nuclear reactions which had been developed by Professor Bohr in the preceding years. They also pointed out that the fragments of the uranium nucleus would fly apart with great energy and this prediction was given a direct proof by experiments carried out by Frisch in Copenhagen. Confirmation of the reality of the fission process with uranium, and of the great energy release which accompanied it, was obtained by Professor Joliot in Paris independently (and at nearly the same time) and by other physicists throughout the world as soon as the original work was known to them.

Very shortly afterwards, in the spring of 1939, Professor Joliot and his collaborators Drs. Halban and Kowarski gave an experimental proof of the additional fact, which was expected on theoretical grounds, that when the fission of

Professor Otto Hahn, the distinguished German scientist, who discovered in 1939 the fission of the uranium nucleus, which led to the atom bomb and the harnessing of atomic energy.

uranium takes place a number of free neutrons is also produced. Their first experiments showed this number to be about three. Experiments of the same types were carried out by Anderson, Fermi, Hanstein, Szilard and Zinn in the U.S.A., and independent confirmation was obtained of the fact that more than one free neutron is produced for each fission of a uranium nucleus.

It was immediately recognized that this discovery was of the very greatest significance and that, for the first time, there was an experimental basis for the hope that the useful realization of the enormous store of atomic energy in matter could be achieved. Not only did the fission reaction provide the large amount of energy that was calculated from the difference in mass of the reactants and products, but the liberation of more than one new neutron each time that a uranium nucleus underwent fission made possible the continuation of the reaction by the development of a chain process once the initial step had been taken. Such a chain process would enable the reaction, in a suitable mass of uranium, to take place at an ever increasing rate and would involve so many atoms that there would be a sensible, and indeed possibly an overwhelming, liberation of energy. The whole process could, furthermore, be started by the application of only a minute fraction of the energy that would be liberated and the difficulty, hitherto encountered in nuclear reactions, of obtaining an overall gain in energy would be eliminated.

It was therefore only natural that there should be an outburst of activity in most of the physics laboratories of the world with a spate of publications in the scientific Press. This continued until the outbreak of war, when an increasing sense of the great potential value of this work imposed restrictions.

Certain important facts emerged from the work that was published during this period and theoretical conclusions and expectations were announced, but it is hardly possible to give any strictly chronological account of them. The work was done in so many laboratories and the results, sometimes in a very preliminary form, were communicated to so many journals and published at such varying intervals after communication, that details of priority cannot be clearly settled. But reference should be made to the visit which Professor Bohr paid to the U.S.A. from January till May, 1939. He

Professor Werner Heisenberg, the leader of German atomic physics. German scientists had almost completed a heavy water atom pile, but the invasion of Europe frustrated this.

was able to report directly to American physicists the experiments carried out by Hahn, Frisch and Meitner and their suggested interpretation of the results. In addition, while in the U.S.A., Bohr developed and published, in collaboration with Professor J. A. Wheeler, of Princeton University, New Jersey, a theory of the fission process.

One important prediction which was made from this theory related to the different behaviour of the various isotopes of uranium. This element consists, for much the greater part (99.3 per cent.), of atoms of mass number 238, but there is also an isotope (0.7 per cent.) of mass 235 and a very small proportion (0.008 per cent.) of an isotope of mass 234. The first two, which are conveniently designated by the symbols U.238 and U.235 respectively, are the most important in connection with the uranium fission project. Bohr predicted, in February, 1939, that the common isotope, U.238, would be expected to undergo fission only when the bombarding neutrons had a high energy but that the rarer U.235 isotope would behave differently in that it would not only show this reaction with high energy neutrons but in addition would be particularly liable to undergo fission when the energy, and therefore the velocity of the bombarding neutrons, was very low. This prediction was, in fact, confirmed in March, 1940, by experiments carried out by Nier, of Minnesota, and Booth, Dunning and Grosse, of Columbia University, New York. They used a sample of uranium in which the content of U.235 had been increased above the normal value by means of Nier's mass-spectrograph.

It is relevant, at this point, to refer to a different phenomenon shown by the U.238 isotope when bombarded by neutrons of one rather narrowly defined energy value which is intermediate between the very high energy required to cause fission of this isotope and the very low energy which is most effective in causing fission of U.235. Neutrons which have this so-called "resonance" energy are very strongly absorbed by the U.238 nucleus but fission does not follow. Instead, the new nucleus, which now has a mass number 239, emits two electrons in successive steps and is thereby converted first to an isotope of an element with atomic number 93 (for which the name "neptunium" has been suggested) and then to one of an element with atomic number 94. This latter has, provisionally, been named ".plutonium" and the isotope formed from U.238 after

resonance capture of a neutron may be represented by the symbol Pu.239. Neptunium and plutonium are true "trans-uranium" elements, of the type suggested by Fermi, and are not found in nature. Of the two, Pu.239 is of particular interest in connection with the general problem of fission and the release of atomic energy because it could be expected, from the Bohr-Wheeler theory, to show the same sort of properties as U.235 and to be capable of undergoing fission with the greatest ease when bombarded by neutrons of very low energy.

Reference must also be made to the fact that the three nuclear species U.235, U.238 and Pu.239 are not the only ones that can undergo fission. The two elements next below uranium in the atomic series were also shown to have this same property. Thorium, with the atomic number 90 and consisting of one isotope only of atomic mass 232, behaves in the same way as U.238 and fission can only be brought about when the bombarding neutrons have very high energy. The very rare radio-active element protactinium, with atomic number 91 and atomic mass 231, behaves, as regards fission, in a manner intermediate between U.235 and U.238. These facts, again, are all explicable in terms of the Bohr-Wheeler theory which enumerates certain general rules covering the behaviour to be expected with regard to fission of any heavy nucleus, known or unknown.

The position then reached may be summarized as follows:—

That three elements—uranium, thorium and protactinium—when bombarded by neutrons sometimes split into approximately equal fragments, and that these fragments were isotopes of elements in the middle of the periodic table, ranging from selenium ($Z=34$) to lanthanum ($Z=57$).

That most of these fission fragments were unstable, decaying radio-actively by successive emission of beta particles through a series of elements to various stable forms.

That these fission fragments had very great kinetic energy.

That fission of thorium and protactinium was caused only by fast neutrons (velocities of the order of thousands of miles per second).

That fission in uranium could be produced by fast or slow (so-called thermal-velocity) neutrons; specifically that thermal neutrons caused fission in one isotope, U.235, but

not in the other U.238, and that fast neutrons had a lower probability of causing fission in U.235 than thermal neutrons.

That at certain neutron speeds there was a large capture cross section in U.238 producing U.239 but not fission.

That the energy released per fission of a uranium nucleus was approximately 200 million electron volts.

That high-speed neutrons were emitted in the process of fission.

That the average number of neutrons released per fission was somewhere between one and three.

That high-speed neutrons could lose energy by inelastic collision with uranium nuclei without any nuclear reaction taking place.

The foregoing survey of the development of atomic and nuclear physics, though necessarily brief and incomplete, has traced the growth of the idea that there are enormous reserves of energy in all matter; that these are of a nature quite different from those involved in chemical processes, such as the burning of coal or oil or the detonation of T.N.T. or other explosives, and that the nuclear reactions by which they are released are more comparable to those occurring in the sun or stars or in the natural radio-active elements found on the earth.

While this idea has been formed and steadily strengthened since the discovery of the phenomenon of radio-activity at the end of last century it is only since the discovery, reported at the beginning of 1939, of the special phenomenon of fission that a way has been clearly seen by which this atomic or nuclear energy in matter could be released, controlled and put to use by man.

CHAPTER II

DECEMBER 2, 1942
THE FIRST REACTOR[1]

AT Chicago, late in the afternoon of December 2, 1942, a small group of scientists witnessed the advent of a new era in science. History was made in what had been a squash-rackets court. Precisely at 3.25 p.m., Chicago time, scientist George Weil withdrew the cadmium-plated control rod and by his action man unleashed and controlled the energy of the atom. An outsider looking into the squash court where the experiment took place, would have been greeted by a strange sight. Shrouded on all but one side by a grey balloon cloth envelope was a pile of black bricks and wooden timbers.

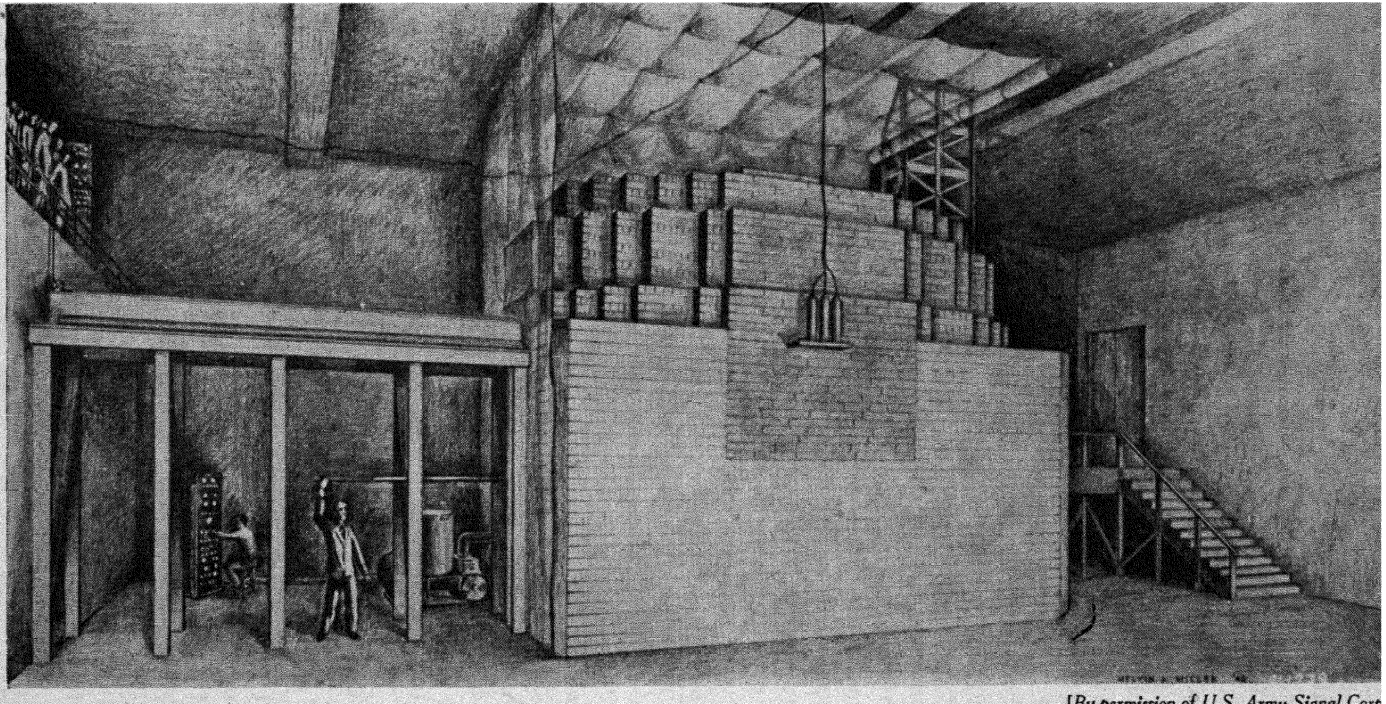
The bag was hung with one side left open; in the centre of the floor a circular layer of graphite bricks was placed. This and each succeeding layer of the pile was braced by a wooden frame. Alternate layers contained the uranium. By this layer-on-layer construction a roughly spherical pile of uranium and graphite was formed.

Before the structure was half complete measurements indicated that the critical size at which the pile would become self-sustaining was somewhat less than had been anticipated in the design.

Day after day the pile grew toward its final shape. As the size of the pile increased, so did the nervous tension of the men working on it. Scientifically they knew that this pile would become self-sustaining. But still, the demonstration had to be made. No matter how well planned there is always a chance that an experiment will not fulfil expectations. So, as the eagerly awaited moment drew nearer, they gave greater and greater attention to details, the accuracy of measurements and exactness of their construction work.

Meanwhile, in Washington, General Groves had proceeded with negotiations with E. I. du Pont de Nemours Company to design, build and operate a plant based on the principles of the Chicago pile. The $350,000,000 Hanford Engineer Works at Pasco, Washington, was to be the result.

[1] Extracts from the official Report of the U.S. Atomic Energy Commission, Commemorating the Fourth Anniversary.



[*By permission of U.S. Army Signal Corp*

Sketch of first self sustaining nuclear chain reactor, operated at Chicago on December 2, 1942. Built on a squash court under the West Stands of Chicago's Stagg Field, it was the first atomic pile.

That night the word was passed to the men who had worked on the pile that the trial run was due the next morning.

About 8.30 on the morning of Wednesday, December 2, the group began to assemble in the squash court.

On the floor of the squash court, just beneath the balcony, stood George Weil, whose duty it was to handle the final control rod. In the pile were three sets of control rods. One set was automatic and could be controlled from the balcony. Another was an emergency safety rod. Attached to one end of this rod was a rope running through the pile, weighted heavily on the opposite end. The rod was withdrawn from the pile and tied by rope to the balcony. A man was ready to cut the rope with an axe should something unexpected happen, or in case the automatic safety rods failed. The third rod, operated by Weil, was the one which actually held the reaction in check until the rod was withdrawn the proper distance.

Since this demonstration was new and different from anything ever done before, complete reliance was not placed on mechanically operated control rods. Therefore a " liquid-control " squad stood on a platform above the pile. They were prepared to flood the pile with cadmium-salt solution in case of mechanical failure of the control rods.

At 9.45 Fermi ordered the electrically operated control rods withdrawn. The man at the controls threw the switch to withdraw them. All eyes watched the lights which indicated the rods' position.

Quickly the balcony group turned to watch the counters, whose clicking stepped up after the rods were out. The indicators of these counters resembled the face of a clock, with " hands " to indicate neutron count. Nearby was a recorder whose pen traced the neutron activity within the pile.

At 11.35, the automatic safety rod was withdrawn and set. The control rod was adjusted. Up went the counters, clicking faster. The graph pen started to climb. Tensely, the little group watched and waited, looking at the climbing needle.

" Pull it out another foot! "

Weil withdrew the rod.

By this time the noise of the counters was a steady brrrrr. Fermi continued his computations and finally closed his slide rule.

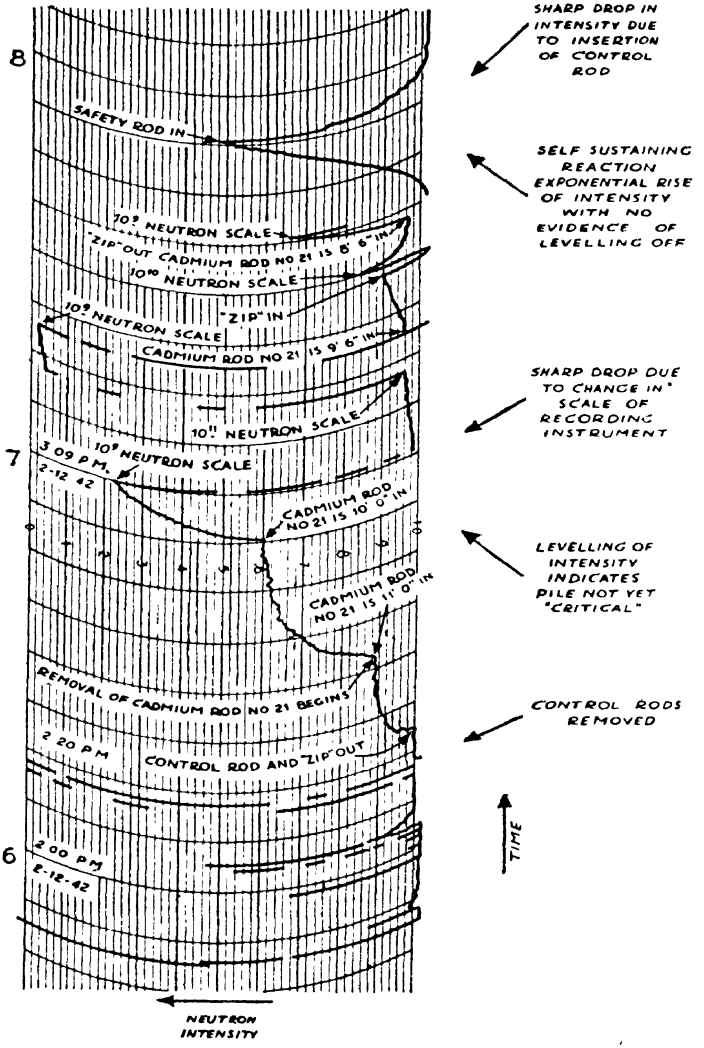


Fig. 1.—Start-up of the first self-sustaining chain reaction neutron intensity in the pile as recorded by a galvanometer.

"The reaction is self-sustaining," he announced quietly.

The group tensely watched for twenty-eight minutes while the world's first nuclear chain reactor operated.

The time was 3.53 p.m. when the control rod entered the pile. Abruptly, the counters slowed down, the pen slipped across the paper. A great experiment was concluded.

Man had initiated a self-sustaining nuclear reaction, and then stopped it. He had released the energy of the atom, and controlled it.

CHAPTER III

ATOMIC ENERGY REACTORS

Preliminary Notes

WHEN we talk about "atomic energy," we are, at the present stage of development, referring solely to the energy obtained from the fission of nuclei derived, directly or indirectly, from uranium and thorium. These materials may be regarded simply as a new type of fuel, an alternative to coal or oil, and similar in the sense that when it "burns," heat is released and in due course converted by conventional means into mechanical power.

There is at present no prospect of harnessing atomic energy in any other way than by utilizing the *heat* it generates. Even in the explosion of an atom bomb, the effect is largely due to the terrific temperature—several million degrees centigrade. Thus the atomic energy of uranium cannot, unfortunately, be converted directly into electrical energy.

The weight of atomic fuel is so small, in all practical applications, that it can be ignored completely. For example, a few hundredweights of plutonium would suffice to propel a large ship for 20 years. On the other hand, the weight of the reactor with its anti-radiation insulation is such that the total weight of an atomic energy plant might even be greater than that of normal plant of the same capacity.

Measured by the capital investment and current expenditure involved, atomic energy is already a major world industry. In the U.S.A. alone over £1,000 millions has been invested in atomic energy plant and current expenditure is at the rate of about £150 millions per annum, employing approximately the same amount of labour as the entire British shipbuilding industry. In Great Britain expenditure is estimated at about £10 millions per annum. Canada may well be in a position to show a credit balance due to the export of uranium and uranium-bearing minerals. No information is available about the activities of the U.S.S.R. except the inevitable rumours. It is certain, however, that atomic development is for Russia a major national effort, and the labour force engaged may well be as large, if not larger, than the U.S.A., Canada and Great Britain combined. In certain quarters it has been suggested that the U.S.S.R. may find difficulty in finding

sufficient scientific and technical personnel of the right calibre, but it must be remembered that the position is different from what it was in 1940 when Great Britain, Canada and the U.S.A. pooled their scientific resources in a concentrated attempt to solve the problem. Since then a vast amount of invaluable data has been released, and even the revelation that atomic power is an established fact gives the U.S.S.R. a short cut of immense value. Nor is Russia likely to be short of raw materials. High-grade ore may not be plentiful but there are certainly vast reserves of low-grade ores.

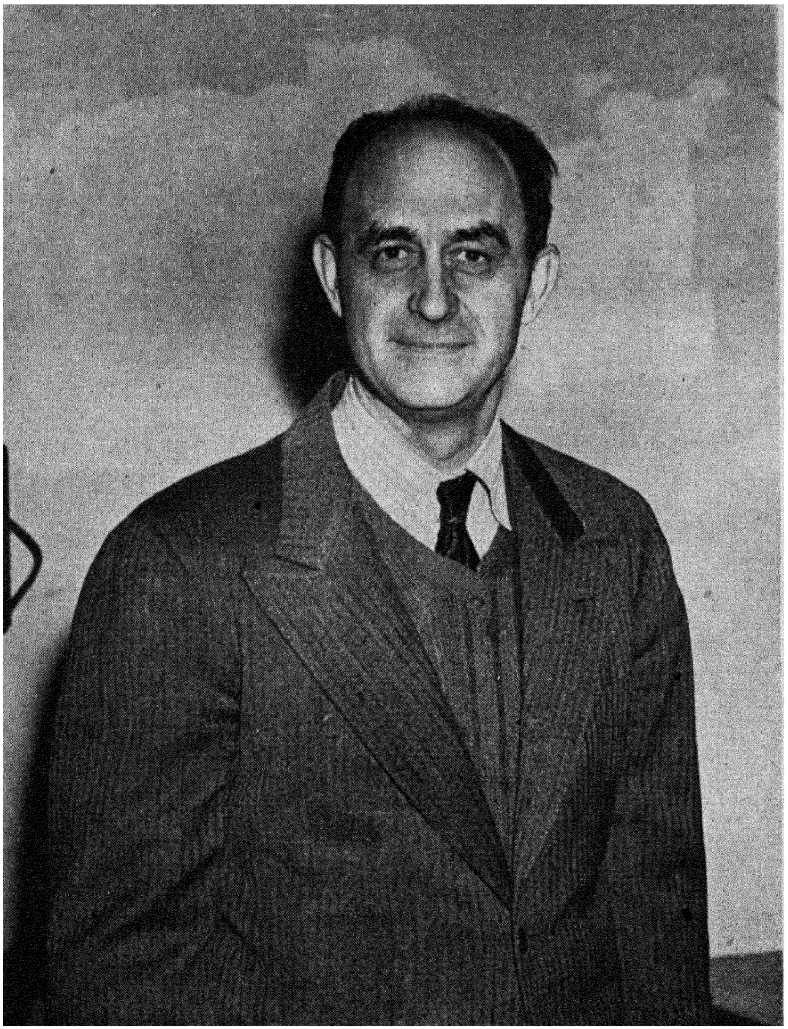
France is developing atomic energy exclusively for industrial purposes, and has her first reactor ready to operate. Belgium is in a very strong position, as the world's richest uranium deposits are in the Belgian Congo with South Africa a close second. Holland and Switzerland are specializing in auxiliary plant, equipment and instruments. Practically every other nation of importance is developing atomic energy as rapidly as possible within its means and capacity.

Day and night, since that memorable date, December 2, 1942, harnessed atomic energy has been silently at work in the U.S.A.

To quote one of the leading American atomic experts, Dr. P. Morrison: "Probably no other machine can be made to operate successfully over such a great range, and stabilized at any desired power level, by the simple motion of a single control lever. The steadiness and smoothness are noteworthy, and why not, for the only moving parts are atoms and neutrons."

One minor problem has been to provide a routine to ensure that the man who is operating the pile does not find it too easy to fall asleep. The normal duties are so slight that the operator has very little to do. Starting and stopping is simply a matter of moving a lever.

In the U.S.A. the three huge Hanford piles, each of over 1,000,000-kW nominal (low temperature) capacity, have been operating continually for some years using ordinary river water for cooling the pile. These great plants were designed from scratch, not as power units but for the production of plutonium, and the only clues the designers had were the data obtained from a minute speck of plutonium and the performance of the relatively tiny Chicago pile, from which the most useful piece of information was the simple fact that it worked! It is certain that there is no parallel to this achievement in the whole history of engineering. The nearest



[*Photo by U.S. Army Signal Corps.*

Professor Enrico Fermi, the distinguished scientist who, on December 2, 1942, started up the world's first atomic energy reactor.

approach to it was probably a marine one, namely Brunel's "Great Eastern," which was an equally daring extrapolation.

Indeed, the engineering industry will inevitably play a vital part, directly and indirectly, in final solutions of the atomic reactor problem, which demand a combined effort by all who are concerned with the handling of fluids and gases at high temperatures and pressures, with pumps, heat exchangers, superheaters and gas turbines, together with all the ancillary items such as insulation, special valves and seals, instruments and electrical plant.

A chain reaction running on purified fissionable materials rather than natural uranium offers many advantages. Since there are fewer atoms of U.238 per fissionable atom of U.235, the capture of neutrons by U.238 is no longer so critical in its effect on the reaction. One can afford to lose more neutrons by other processes without stopping the chain reaction. This permits a great increase in the ease of construction and operation of the plant. For one thing it can be made smaller, because greater freedom of design permits a larger fraction of the volume to be occupied by cooling pipes and other engineering features.

Small size is not necessarily an advantage when a great deal of energy is required from a chain reaction. The difficulty of removing a large amount of energy rapidly from a small space is a well-known engineering problem of heat transfer. The power available from a chain reaction is limited essentially, only by the rate that energy can be removed. As sources of power, therefore, large reactors have the advantage that more energy can be removed from them in a given time.

From the nucleonic angle, a reactor can theoretically be stabilized at any power level, that is it can gradually be brought up to a particular level by using a multiplication factor slightly in excess of unity, making use of the delayed neutrons to prevent the reaction running away, and then levelling off at the desired level, with a stabilized multiplication factor of unity.

If energy is not the prime concern, small chain reactors can be made by mixing separated U.235 or plutonium with heavy water to slow down the neutrons, thereby making them more efficient in producing fission. With such purified materials the capture of neutrons by impurities is not very great. Therefore a considerable loss of neutrons by leakage can be tolerated. A chain reaction can thus be maintained

[*Photo by U.S. Army Signal Corps.*

Professor W. H. Zinn, who collaborated with Fermi in the design and operation of the first reactor, and is now head of the Argonne Laboratory.

in a relatively small volume if fissionable materials are available in a purified form. Amounts of material which are only a fraction of the material needed for an atomic bomb can be used. These reactors are not useful for large energy release because of the difficulties of the removal of considerable quantities of energy from a small space. The Los Alamos " water-boiler " was probably the first reactor of the miniature type.

These small reactors are very useful research tools in that they generate a copious supply of neutrons. The effect of the neutrons on various substances and on living things can be studied. As a result of intense neutron irradiation, it is known that many materials change their physical properties. The small chain reactor can also be used to produce small amounts of radioisotopes. In addition, many radioactive materials last such a short time that it may be very desirable to produce them on the spot in the laboratory in which they will be used.

The functions of the different types of atomic energy reactor may broadly speaking be distinguished as follows:—

A. Experimental Reactors, for example for establishing data, testing the effect of variations in design and the effect of radiation on materials:
   (a) Slow reactors. (b) Fast reactors.
B. Laboratory Reactors for the production of radioisotopes, stable isotopes and active materials for special purposes such as gamma radiation as an alternative to X rays.
C. Medium Reactors for the production of low temperature heat for hot water, steam or air heating.
D. Primary Reactors for the production of concentrated fissible materials: Pu.239 or U.233.
E. Primary Reactors for the generation of electric power.
F. Medium Reactors for the production of high temperature heat for industrial processes, or for marine propulsion.

Types E. and F. may be very similar in design, except that Type E. is normally much larger. Types C. and D. may also be similar, except perhaps in size. In the present state of knowledge all these reactors would use natural uranium with or without natural thorium added. Some experimental reactors would, of course, be designed to use concentrated fuel: Type A. (b), and in due course, when adequate supplies of concentrated fuel can be guaranteed, secondary reactors

for industrial and marine purposes will become practicable. It is important to note that with natural uranium, or uranium plus thorium, the reactor starts up by burning the U.235 isotope only. The design must therefore be such as to permit the chain reaction to start under these conditions. As the reaction proceeds, and the U.235 is slowly consumed, active Pu.239 and U.233 is gradually produced by conversion of the inactive U.238 and Th.232. If there were exactly *two* neutrons produced by each fission of U.235, Pu.239 or U.233, the reaction could theoretically continue until the whole of the inactive material had been converted.

In practice, the neutron losses due to escape through the walls of the reactor and absorption by the materials and instruments and fission products, give a value inevitably less than two, but not less than one, for the *effective* number of neutrons released per fission. When the reactor is absolutely steady the neutron muliplication factor is exactly unity, irrespective of the power level. This fact is fundamental to all reactor design at present. Further, if we have a reactor with an initial charge of, say, 1,000 tons of natural uranium, of which about seven tons would be represented by active U.235, we cannot use up all the uranium, because the reactor will reach a peak intensity and then gradually "peter out," when nearly all the U.235 has gone, and there is not sufficient Pu.239 left to maintain the reaction. Before this stage is reached, the uranium charge must be withdrawn and the reactor must be recharged.

The partly consumed uranium should then be processed for the extraction of the extremely precious plutonium content. Indeed, the big Hanford piles in the U.S.A. are operated for no other purpose. The extraction process is, however, difficult, dangerous and costly. It is a serious disadvantage for any medium size commercial reactor, and this could only be mitigated by having a central treatment plant for extraction of plutonium from partly burnt uranium, which would have to be transported to the central plant in small amounts shielded by very heavy containers, even after being allowed to "cool" for a period at the reactor site. Note also that the uranium from which the plutonium has been extracted has also lost all or most of its active U.235, so that it would be useless for recharging, unless it were introduced as a weak "dilution," so as not to interfere unduly with the chain reaction.

Thus, apart from the starting up condition, a reactor must also be designed for an operating condition which is normally not steady but cyclic. This, in practice, is not so difficult as it may appear at first sight. If the uranium is in the form of rods, it is possible to determine the optimum period of time for the rod to remain in the pile. When the reactor is automatically stabilized, the rods may be removed in a predetermined rotation at regular intervals, so that the power level of the reactor is not appreciably affected. The rods are automatically handled by remote control, the burnt rod being removed and a new rod inserted at regular intervals. The life of a particular rod will depend on the power level, but would normally be of the order of a few weeks, and as there may be some hundreds of rods, the difficulties of loading and unloading are not prohibitive.

The ideal reactor would, of course, be one in which the fuel could be continuously injected into the combustion space and the waste products continuously exhausted—indeed in a somewhat similar manner to an internal-combustion engine.

In this way, a unit could be designed as a medium-fast reactor, the initial charge containing concentrated fuel diluted with natural uranium to the point at which the concentration is just sufficient to start-up the reaction. As the reaction proceeds, in this " ideal " type of reactor, *natural* uranium would be injected continuously in small quantities to provide a continual flow of new nuclei, to make up for the nuclei destroyed. In this way, once the reactor has been given an initial charge, it can be operated automatically at an *equilibrium* condition, using a make-up fuel feed of natural uranium only, but of exactly the same amount as if it were plutonium or 235. If the design factors were correctly worked out, the reactor would start up from the equilibrium condition with a greater margin in hand than from the assumed initial condition, which pre-supposes the use of the minimum amount of plutonium or 235, the cost of which is even now unpredictable.

With such a reactor there need be no plutonium recovery problem because, over a period, all the plutonium nuclei would be " burnt."

Now it is known that a natural uranium reactor will maintain a chain reaction on less than six tons of metal, the initial fuel contact of which is given by the U.235 percentage, that is 0.7 per cent. or, say, 90 lb. It follows that a U.235

or plutonium reactor suitably designed would operate with an initial fuel charge of considerably less than 90 lb. For a power output equivalent to 30,000 b.h.p., allowing 10 per cent. overall efficiency as an ultra conservative figure, the fuel nuclei would be " burnt " at the rate of less than 0.03 lb. per hour, and this also represents the hourly rate of feed of make-up fuel, that is a dilution at the rate of 0.03 lb. of natural uranium for 30,000 b.h.p. net.

If the U.238 nucleus is to be transformed by neutron capture into a Pu.239 nucleus, the incident neutron must be slowed down to a known range of speed at which natural uranium shows a very strong resonant absorption for neutrons. Thus a moderating medium must be introduced into the reactor to diminish the chance of fast fission of the natural uranium and to enhance the chance of neutron capture and conversion to plutonium. The moderator problem in this case is therefore different and simpler than for a natural uranium " pile," where the neutron energy must be reduced as rapidly as possible to *avoid* excessive capture by U.238, otherwise the chain reaction would fail to start. If the neutrons in a medium-fast reactor can be prevented from escaping by surrounding the reactor with an efficient neutron reflector, it is conceivable that the free path of the neutron in the reactor might be greatly increased, with a corresponding increase in the probability of its energy being reduced sufficiently for resonant capture.

The starting up and control of an atomic plant present some interesting features. A single free neutron is needed to start the chain reaction. How is this introduced into a " dead " pile? A minute speck of radium-beryllium mixture would be sufficient, but in practice this is not necessary, owing to the remarkable phenomenon of spontaneous fission: in a given mass of uranium, a few nuclei per second undergo fission without any external influence, not even a " cold " neutron. This then is the source of the neutron which starts up the reactor immediately the neutron-absorbing control rods are withdrawn. The same control rods are used to stabilize the energy output of the reactor at any desired power level. Nature has been kind here: a proportion of the fission neutrons are delayed in emission by periods ranging from 2 to 60 seconds and this enables the neutron reproduction rate to be gradually raised without the reaction " running away." The delayed neutron effect is the explanation for

the extraordinarily smooth and sensitive control, and permits the power level to be stabilized within limits of one part in one thousand.

We now come to the big problem—probably the most serious obstacle to be overcome in harnessing atomic energy—how to extract the heat generated in the reactor. It is no doubt fair to say that when the atom bomb proved that the chain reaction would work, and release enormous sources of energy, and pile operation showed that the rate of energy release could be controlled, many competent scientists and engineers assumed that it would be a relatively simple matter to extract the heat by conventional methods, and at convenient temperatures. It has proved a baffling problem, and may have to be solved the hard way, that is by prolonged and patient development, unless a flash of inspiration appears.

In brief, the difficulty of extracting heat at a level which would, for example, produce steam or gas at 1,000 degrees F. for efficient power production, is due to a combination of many factors, *some* of which are as follows:—

1. AIR COOLING.—(a) Rapid oxidation of uranium at high temperatures; (b) high neutron absorption of nitrogen weakens chain reaction; (c) danger of leakage of radio-active gas at high pressure.

2. WATER COOLING.—(a) Rapid corrosion of uranium in water even at low temperature; (b) difficulty of sheathing the uranium and maintaining satisfactory heat transfer; (c) radio-activity induced in the water.

3. HELIUM COOLING.—Helium has the advantage of not absorbing neutrons, not becoming radio-active, not causing oxidation or chemical reactions, has excellent heat transfer properties. On the other hand, it demands a closed circuit which would carry, eventually, a continuous load of radio-active impurities, and even minute leakage might be intolerable. Large quantities would be required. It is at present scarce and expensive.

4. ALTERNATIVE METHODS.—The possibilities are rather limited—for example CO_2 or helium mixed with CO_2. Liquid bismuth has been seriously considered.

5. TUBES AND SHEATHING.—Aluminium was completely successful at moderate temperatures, but is not ideal at higher temperatures. The tubes must be of material which does not disintegrate under heavy radiation and at the same time must meet all the ordinary requirements of tubes for

the duty in question. In addition the neutron absorption must be low. Some elements acceptable in this respect are lead, bismuth, beryllium, aluminium, magnesium, zinc, and tin. Some new radiation-stable alloy of two or more of these might solve the problem. Failing this, the reactor must have an increased margin on the maintenance of the chain reaction, to permit of a material satisfactory from the engineering and metallurgical points of view, at the expense of nuclear-physical characteristics. This margin is probably obtainable only with a reactor burning enriched fuel.

6. Irrespective of the type of heat extraction system adopted, arrangements must be made so that if any failure in flow occurs, the chain reaction is stopped *instantaneously*. There is, however, no difficulty here—such a control is a stand-by at the Hanford piles, but with a working temperature several hundred degrees higher, it may be necessary to make the control even more sensitive.

The foregoing gives a brief survey of the vitally important heat extraction problem. By comparison, the other major problems are of less interest to the engineer than to the physicist, the metallurgist or the chemist. For example, the neutron moderator is largely a matter for the physicist: for a low temperature solid moderator, graphite is acceptable; if liquid, heavy water. Here again a moderator for a high temperature reactor may have to sacrifice ideal nuclear properties in favour of heat-resisting properties. Suitable materials for the shielding are less difficult to find. For a land installation about 5 ft. of concrete is sufficient. For a marine plant where space is valuable, equivalent metal shielding would be preferable.

From what has been said earlier about radio-activity effects, it will be expected that relatively meticulous precautions have to be taken, in designing plant details and by personnel operating the plant.

There are, of course, many industries to-day where those employed must take essential precautions to protect themselves and their fellow workers. Atomic energy is only different in the type of risk involved and the degree of care with which regulations must be observed. A simple basic precaution is that each employee shall carry a radiation-indicating badge or pocket instrument. A monitoring service can then be operated and any employee carrying a radiation count, however far below the tolerance limit, can be

immediately checked. It is significant to note that from the very wide experience of these methods already gained in the U.S.A., the safety record is quite remarkable.

In a conventional reactor, the main features and factors considered may be summarized as follows:—

1. Functions of proposed reactor.
2. Maximum power level.
3. Type of nuclear fuel.
4. Processing of fuel.
5. Neutron moderator.
6. Arrangement of fuel in reactor.
7. Net dimensions and form of reactor.
8. Type of shielding. Overall dimensions and form of unit.
9. Neutron reflector.
10. Neutron reproduction factors.
11. Heat extraction system.
12. Loading and unloading of fuel.
13. Processing of fuel residue for concentrates.
14. Disposal of solid fission products.
15. Disposal of gaseous fission products.
16. Disposal of radio-active working fluids.
17. Stability of materials when exposed to radiations, and at working temperatures.
18. Reactor materials: purity standards.
19. Starting, stopping and control of chain reaction.
20. Instrumentation.
21. Thermal, mechanical and chemical control of working fluids.
22. Control of gamma, beta and neutron radiation.
23. Safety precautions.
24. Maintenance.
25. Ancillary plant and buildings.
26. Technical personnel.
27. Maintenance of fuel supply.
28. Operating cost.
29. Capital cost.

This somewhat formidable list will, of course, become largely a routine matter as familiarity with atomic energy plant breeds confidence and some degree of standardization.

It will be evident that in the present state of knowledge, until some basically different type of reactor is developed, the

development of a reliable and trouble-free unit may demand the use of fuel enriched with fissionable concentrate.

There is indeed every indication that design will develop towards the perfection of a compromise between the "slow" reactor such as the cumbersome natural uranium pile, and the "fast" reactor, such as an atom bomb. The foregoing explanation of some of the fundamental factors, shows how wide is the scope for research and inventive genius in this new field.

The Chain Reaction

In some respects it is true to say that we now know more about what is happening to the neutrons inside an atomic energy reactor than we do about the behaviour of the hydrocarbon molecules inside the combustion space of an internal-combustion engine. As an introduction to the chain reaction process we present a précis of the relevant sections of the famous Smyth report. This report is so clear and concise that it is a classic of its kind.

The principle of operation of an atomic power plant utilizing uranium fission is simple enough. If one neutron causes a fission that produces more than one new neutron, the number of fissions may increase tremendously with the release of enormous amounts of energy. It is a question of probabilities. Neutrons produced in the fission process may escape entirely from the uranium, may be captured by uranium in a process not resulting in fission, or may be captured by an impurity. Thus the question of whether a chain reaction does or does not develop depends on the result of a competition among four processes:—

(1) escape,
(2) non-fission capture by uranium,
(3) non-fission capture by impurities,
(4) fission capture.

If the loss of neutrons by the first three processes is less than the surplus produced by the fourth, the chain reaction occurs; otherwise it does not. Evidently any one of the first three processes may have such a high probability in a given arrangement that the extra neutrons created by fission will be insufficient to keep the reaction going. For example, should it turn out that process (2)—non-fission capture by

uranium—has a much higher probability than fission capture, there would be no possibility of achieving a chain reaction.

An additional complication is that the probabilities of processes (2) and (4) are different for different isotopes, and are different for neutrons of different energies.

The relative number of neutrons which escape from a quantity of uranium can be minimized by changing the size and shape of the pile. In a sphere, any surface effect is proportional to the square of the radius, and any volume effect is proportional to the cube of the radius. Now the escape of neutrons from a quantity of uranium is a surface effect depending on the area of the surface, but fission capture occurs throughout the material and is therefore a volume effect. Consequently the greater the amount of uranium, the less probable it is that neutron escape will predominate over fission capture and prevent a chain reaction. Loss of neutrons by non-fission capture is a volume effect like neutron production by fission capture, so that increase in size makes no change in its relative importance.

The critical size of a device containing uranium is defined as the size for which the production of free neutrons by fission is just equal to their loss by escape and by non-fission capture. In other words, if the size is smaller than critical, then—by definition—no chain reaction will sustain itself.

Thermal neutrons have the highest probability of producing fission of U.235, but the neutrons emitted in the process of fission have high speeds. It is an over-simplification to say that the chain reaction might maintain itself if more neutrons were created by fission than were absorbed. For the probability both of fission capture and of non-fission capture depends on the speed of the neutrons. Unfortunately, the speed at which non-fission capture is most probable is intermediate between the average speed of neutrons emitted in the fission process and the speed at which fission capture is most probable.

For some years before the discovery of fission, the customary way of slowing down neutrons was to cause them to pass through material of low atomic weight, such as hydrogenous material. It was E. Fermi and L. Szilard who proposed the use of graphite as a moderator for a chain reaction. The process of slowing down or moderation is simply one of elastic collisions between high-speed particles and particles practically at rest. The more nearly indentical the masses

of neutron and struck particle, the greater the loss of kinetic energy by the neutron. Therefore the light elements are most effective as "moderators," i.e., slowing-down agents, for neutrons.

It occurred to a number of physicists that it might be possible to mix uranium with a moderator in such a way that the high-speed fission neutrons, after being ejected from uranium and before re-encountering uranium nuclei, would have their speeds reduced below the speeds for which non-fission capture is highly probable. Evidently the characteristics of a good moderator are that it should be of low atomic weight and that it should have little or no tendency to absorb neutrons. Lithium and boron are excluded on the latter count. Helium is difficult to use because it is a gas and forms no compounds. The choice of moderator therefore lay among hydrogen, deuterium, beryllium and carbon. Even now no one of these substances can be excluded from the list of practical possibilities.

The general scheme of using a moderator mixed with the uranium was obvious. A specific manner of using a moderator was first suggested, so far as we can discover, by Fermi and Szilard. The idea was to use lumps of uranium of considerable size embedded in a matrix of moderator material. Such a lattice can be shown to have real advantages over an homegeneous mixture. As the constants were more accurately determined, it became possible to calculate theoretically the type of lattice that would be most effective.

For neutrons of certain intermediate speeds (corresponding to energies of a few electron volts) U.238 has a large capture cross section for the production of U.239 but not for fission. There is also a considerable probability of inelastic (i.e., non-capture-producing) collisions between high-speed neutrons and U.238 nuclei. Thus the presence of the U.238 tends both to reduce the speed of the fast neutrons and to effect the capture of those of moderate speed. Although there may be some non-fission capture by U.235, it is evident that if we can separate the U.235 from the U.238 and discard the U.238, we can reduce non-fission capture and can thus promote the chain reaction. In fact, the probability of fission of U.235 by high-speed neutrons may be great enough to make the use of a moderator unnecessary once the U.238 has been removed. Unfortunately, the U.235 is present in natural uranium only to the extent of about one part in

140. Also, the relatively small difference in mass between the two isotopes makes separation difficult.

The cross section for capture of neutrons varies greatly among different materials. In some it is very high compared with the maximum fission cross section of uranium. If, then, we are to hope to achieve a chain reaction, we must reduce effect (3)—non-fission capture by impurities—to the point where it is not serious. This means very careful purification of the uranium metal and very careful purification of the moderator. Calculations show that the maximum permissible concentrations of many impurity elements are a few parts per million—in either the uranium or the moderator.

About 1 per cent. of the neutrons emitted in fission processes are not ejected immediately but are given off in decreasing quantity over a period of time, a fact reminiscent of the emission of beta rays from short-lived radioactive substances. Several half-lives had been observed, the longest being of the order of a minute.

This time delay gives a sort of inertia to the chain reaction that greatly facilitates control. If the effective multiplication factor of a pile became slightly greater than one, the neutron density would not rise to harmfully large values almost instantly but would rise gradually so that there would be a chance for controls to operate. (Other time intervals involved, such as those between collisions, are too small to be useful.) The results indicated that 1.0 per cent. of the neutrons emitted in uranium fission are delayed by at least 0.01 second and that about 0.07 per cent. are delayed by as much as a minute. By designing a pile such that the effective value of k, the multiplication factor, is only 1.01 the number of delayed neutrons is sufficient to allow easy control.

The problem of control is different, depending on whether we are interested in steady production of power or in an explosion. In general, the steady production of atomic power requires a slow-neutron-induced fission chain reaction occurring in a mixture or lattice of uranium and moderator, while an atomic bomb requires a fast-neutron-induced fission chain reaction in U.235 or Pu.239, although both slow- and fast-neutron fission may contribute in each case.

The operation of a pile depends on the passage of neutrons through matter and on the nature of the collisions of neutrons with the nuclei encountered. The collisions of principal importance are the following:—

1. Collisions in which neutrons are scattered and lose appreciable amounts of energy.

   (a) Inelastic collisions of fast neutrons with uranium nuclei.

   (b) Elastic collisions of fast or moderately fast neutrons with the light nuclei of the moderator material; these collisions serve to reduce the neutron energy to very low (so-called thermal) energies.

2. Collisions in which the neutrons are absorbed.

   (a) Collisions which result in fission of nuclei and give fission products and additional neutrons.

   (b) Collisions which result in the formation of new nuclei which subsequently disintegrate radioactivily. (e.g., 92.U.239 which produces 94.Pu.239.)

Only the second class of collision requires further discussion. As regards collisions of type II(a), the most important in a pile are the collisions between neutrons and U.235, but the high energy fission of U.238 and the thermal fission of Pu.239 also take place. Collisions of type II(b) are chiefly those between neutrons and U.238. Such collisions occur for neutrons of all energies, but they are most likely to occur for neutrons whose energies lie in the "resonance" region located somewhat above thermal energies. The sequence of results of the type II(b) collision is represented as follows:—

92.U.238 + n $\longrightarrow$ 92.U.239 + gamma ray.

(23 min.) 92.U.239 $\longrightarrow$ 93.Np.239 + beta ray.

(2-3 days) 93.Np.239 $\longrightarrow$ 94.Pu.239 + beta ray + gamma ray.

Any other non-fission absorption processes are important chiefly because they waste neutrons; they occur in the moderator, in U.235, in the coolant, in the impurities originally present, in the fission products, and even in plutonium itself.

If the object of the chain reaction is to generate plutonium, we would like to absorb all excess neutrons in U.238, leaving just enough neutrons to produce fission and thus to maintain the chain reaction. Actually the tendency of the neutrons to be absorbed by the dominant isotope U.238 is so great compared with their tendency to produce fission in the 140-times-rarer U.235 that the principal design effort must be directed

towards favouring the fission (as by using a moderator, a suitable lattice, materials of high purity, etc.), in order to maintain the chain reaction.

Most chain-reacting piles consist of four categories of material—the uranium metal, the moderator, the coolant, and the auxiliary materials such as water tubes, casings of uranium, control strips or rods, impurities, etc. All the piles depend on stray neutrons from spontaneous fission or cosmic rays to initiate the reaction.

Suppose that the pile were to be started by simultaneous release (in the uranium metal) of N high-energy neutrons. Most of these neutrons originally have energies above the threshold energy of fission of U.238. However, as the neutrons pass back and forth in the metal and moderator, they suffer numerous inelastic collisions with the uranium and numerous elastic collisions with the moderator, and all these collisions serve to reduce the energies below that threshold. Specifically, in a typical graphite-moderated pile a neutron that has escaped from the uranium into the graphite travels on the average about 2.5 cm. between collisions and makes on the average about 200 elastic collisions before passing from the graphite back into the uranium. Since at each such collision a neutron loses on the average about one-sixth of its energy, a one Mev neutron is reduced to thermal energy (usually taken to be 0.025 electron volt) considerably before completing a single transit through the graphite. There are, of course, many neutrons that depart from this average behaviour, and there will be enough fissions produced by fast neutrons to enhance slightly the number of neutrons present. The enhancement may be taken into account by multiplying the original number of neutrons N by a factor ϵ which is called the fast-fission effect or the fast-multiplication factor.

As the average energy of the $N\epsilon$ neutrons present continues to fall, inelastic collision in the uranium becomes unimportant, the energy being reduced essentially only in the moderator. However, the chance of non-fission absorption (resonance capture) in U.238 becomes significant as the intermediate or resonance energy region is reached. Actually quite a number of neutrons in this energy region will be absorbed regardless of choice of lattice design. The effect of such capture may be expressed by multiplying $N\epsilon$ by a factor p (which is always less than one) called the "resonance escape probability," which is the probability that a given neutron starting with

energy above the resonance region will reach thermal energies without absorption in U.238. Thus from the original N high-energy neutrons we obtain $N\epsilon p$ neutrons of thermal energy.

Once a neutron has reached thermal energy the chance of its losing more energy by collision is no greater than the chance of its gaining energy. Consequently the neutrons will remain at this average energy until they are absorbed. In the thermal-energy region the chance for absorption of the neutron by the moderator, the coolant and the auxiliary materials is greater than at higher energies. At any rate it is found that we introduce little error into our calculations by assuming all such unwanted absorption takes place in this energy region. We now introduce a factor f, called the thermal utilization factor, which is defined as the probability that a given thermal neutron will be absorbed in the uranium. Thus from the original N fast neutrons we have obtained $N\epsilon pf$ thermal neutrons which are absorbed by uranium.

Although there are several ways in which the normal mixture of uranium isotopes can absorb neutrons, we define a quantity η which is the number of fission neutrons produced for each thermal neutron absorbed in uranium regardless of the details of the process. If, therefore, we multiply the number of thermal neutrons absorbed in uranium $N\epsilon pf$ by η we have the number of new high-speed neutrons generated by the original N high-speed neutrons in the course of their lives. If $N\epsilon pf\eta$ is greater than N, we have a chain reaction, and the number of neutrons is continually increasing. Evidently the product $\epsilon pf\eta = k$, the multiplication factor already defined, for a pile of, theoretically, infinite size.

Note that no mention has been made of neutrons escaping from the pile. Such mention has been deliberately avoided since the value of k as defined above applies to an infinite lattice. From the known values of k and the fact that these piles do operate, one finds that the percentage of neutrons escaping cannot be very great. The escape of neutrons becomes relatively less important as the size of the pile increases. If it is necessary to introduce in the pile a large amount of auxiliary material, such as cooling-system pipes, it is necesssary to build a somewhat larger pile to counteract the increase in absorption.

The average distribution of *energy* arising from the various processes operating in a chain reacting pile is summarized

by Goodman (Nucleonics, November 1947, p. 26) as follows:

	Per Cent.
Fission Fragments	80
Neutrons	
Prompt	2
Delayed	.004
Gamma Rays	
Prompt	2
Radioactivity	3
Neutron absorption	4
Beta Rays	
Radioactivity	3
Neutrons	
Radioactivity	6

To sum up, a pile operates by reducing high-energy neutrons to thermal energies by the use of a moderator lattice arrangement, then allowing the thermal-energy neutrons to be absorbed by uranium, causing fission which regenerates further high-energy neutrons. The regeneration of neutrons is aided slightly by the fast neutron effect; it is impeded by resonance absorption during the process of energy reduction, by absorption in graphite and other materials, and by neutron escape.

Even at high-power level, only a few grams of U.238 and of U.235 are used up per day per million grams of uranium present. Nevertheless, the effects of these changes are very important. As the U.235 is becoming depleted the concentration of plutonium is increasing. Fortunately plutonium itself is fissionable by thermal neutrons and so tends to counterbalance the decrease of U.235 as far as maintaining the chain reaction is concerned. However, other fission products are being produced also.

When a U.235 nucleus undergoes fission it emits one or more neutrons and splits into two fragments of comparable size and of total mass 235 or less. Apparently fission into precisely equal masses rarely occurs, the most abundant fragments being a fragment of mass number between 134 and 144 and a fragment of mass number between 100 and 90. Thus there are two groups of fission products: a heavy group with mass numbers extending approximately from 127 to 154, and a light group from approximately 115 to 83. These fission products are in the main unstable isotopes of the thirty or so known elements in these general ranges of mass number.

Typically they decay by successive beta emissions accompanied by gamma radiation finally to form known stable nuclei. The half-lives of the various intermediate nuclei range from fractions of a second to a year or more; several of the important species have half-lives of the order of a month or so. About twenty different elements are present in significant concentration; the most abundant of these comprises slightly less than 10 per cent. of the aggregate.

In addition to radioactive fission products, U.239 and Np.239 (intermediate products in the formation of plutonium) are present in the pile and are radioactive. The concentrations of all these products begin to build up at the moment the pile starts operating. Eventually the rate of radioactive decay equals the rate of formation so that the concentrations become constant. For example, the number of atoms of U.239 produced per second is constant for a pile operating at a fixed power level. According to the laws of radioactive disintegration, the number of U.239 atoms disappearing per second is proportional to the number of such atoms present and is thus increasing during the first few minutes or hours after the pile is put into operation. Consequently there soon will be practically as many nuclei disintegrating each second as are formed each second. Equilibrium concentrations for other nuclei will be approached in similar manner, the equilibrium concentration being proportional to the rate of formation of the nucleus and to its half-life. Products which are stable or of extremely long half-life (e.g., plutonium) will steadily increase in concentration for a considerable time. When the pile is stopped, the radioactivity, of course, continues, but at a continually diminishing absolute rate. Isotopes of very short half-life may "drop out of sight" in a few minutes or hours; others of longer half-life keep appreciably active for days or months. Thus at any time the concentrations of the various products in a recently stopped pile depend on what the power level was, on how long the pile ran, and on how long it has been shut down. Of course, the longer the pile has run, the larger is the concentration of plutonium and (unfortunately) the larger is the concentration of long-lived fission products. The longer the "cooling" period, i.e., the period between removal of materials from the pile and chemical treatment, the lower is the radiation intensity from the fission products. A compromise must be made between such considerations as the desire for a long running

and cooling time on the one hand and the desire for early extraction of the plutonium on the other hand.

Tables can be prepared showing the chemical concentrations of plutonium and the various fission products as functions of power level, length of operation, and length of cooling period. The half-life of the U.239 is so short that its concentration becomes negligible soon after the pile shuts down. The neptunium becomes converted fairly rapidly to plutonium. Of course, the total weight of fission products, stable and unstable, remains practically constant after the pile is stopped.

An effective heat engine must not only develop heat but must develop heat at a high temperature. To run a chain-reacting system at a high temperature and to convert the heat generated to useful work is very much more difficult than to run a chain-reacting system at a low temperature.

Three ways of increasing the likelihood of a chain reaction have been mentioned; use of a moderator; attainment of high purity of materials; use of special material, either U.235 or Pu.239. The three procedures are not mutually exclusive, and many schemes have been proposed for using small amounts of separated U.235 or Pu.239 in a lattice composed primarily of ordinary uranium or uranium oxide and of a moderator or two different moderators. Such proposed arrangements are usually called " enriched piles."

It is known that both thorium and protoactinium also undergo fission when bombarded by high-speed neutrons. The great advantage of uranium, at least for preliminary work, is its susceptibility to slow neutrons. Protoactinium can be eliminated because of its scarcity in nature. Thorium is relatively plentiful but has no apparent advantage over uranium.

It is not to be forgotten that theoretically many nuclear reactions might be used to release energy. At present we see no way of initiating or controlling reactions other than those involving fission.

Moderator Materials
Graphite, Heavy Water and Beryllium

An essential feature of a nuclear reactor is a neutron moderator, and, as we have seen, the essential properties of the material of the moderator are (a) relatively low atomic

weight, and (b) minimum neutron absorption. Elements which are acceptable are relatively few, the important ones being hydrogen, deuterium, beryllium and carbon. Deuterium is superior to hydrogen in respect to neutron absorption, hence the demand for heavy water. Carbon in the form of highly purified graphite is a most useful moderating material. It is used in the form of blocks finished to extremely accurate dimensions. The production processes involved are not negligible. It is probable that eventually moderators will be synthesized from pure carbon and deuterium to form a convenient hydro-carbon or organic substance. " Heavy " paraffin and other compounds embodying deuterium have already been manufactured. There is, in fact, likely to be a rapid increase in the demand for heavy water as the atomic age advances. There is a unique reward awaiting the inventor who can readily separate in large quantities these two atoms of hydrogen, one of which is twice as heavy as the other.

For a power-producing reactor we must apparently rule out heavy water, and probably graphite, as at present used. The moderator must have heat-resisting properties, a high melting point, be stable at elevated temperatures, and have reasonable physical properties such as hardness and strength. Fortunately beryllium metal and beryllium oxide both possess these qualities, but both are at present very costly materials. In 1945 the U.S. stockpile of beryl ore—containing about 10 per cent. beryllium metal—was 4,500 tons and the estimated consumption 1,200 tons. Extensive use of beryllium as a pile moderator would not, therefore, be possible without a considerable expansion in mining and prospecting for new sources.

The only mineral at present regarded as a commercial source of beryllium is beryl, a beryllium aluminium silicate occurring in granite veins. The leading U.S.A. specialists are the Brush Beryllium Co., of Cleveland, Ohio.

The properties of beryllium are quite remarkable: it is about as light as magnesium, but has a modulus of elasticity greater than that of steel. Its chemical stability is similar to aluminium, but its melting point is far higher and approaches that of iron. The strongest copper-base and nickel-base alloys are both formed with 2 per cent. beryllium.

Finally, beryllium is a prolific source of neutrons under bombardment, the classical source being a radium-beryllium

mixture giving an (α, n) reaction. Fast neutrons give an (n, 2n) reaction which pays a dividend on neutron capture in favour of the neutron multiplication factor.

For beryllium there is even neutron emission under gamma ray bombardment by (γ, n) reactions. These facts explain the intense interest in beryllium, its properties and alloys, for atomic energy power production.

CHAPTER IV

BY-PRODUCTS OF ATOMIC ENERGY

Applications to Industry

UNDERLYING the entire field of atomic energy are the two big questions: how soon can it be harnessed for industry, and how long will it last when it *has* been harnessed? These questions are peculiarly interlocked: the availability of fissionable materials depends not only on the stores in the earth's surface, but on the time and energy consumed in obtaining them in quantities sufficient to permit full-scale economic development of atomic energy.

The answer may lie in one of several directions: (a) discovery of new deposits; (b) improvement in recovery processes; (c) more efficient utilization of available material; (d) discovery of fundamentally new methods of creating a chain reaction using other elements as primary fission sources or as fissionable dilutions.

But, apart from power production, atomic energy has important reactions on many other spheres of human effort, and in so far as these are not governed by engineering problems or by the inevitable depletion of the world reserves of uranium and thorium, their effects may be more immediate and also more long-lived. For example, in industry, chemistry, metallurgy, agriculture and medicine the by-products of atomic energy have already achieved notable advances.

These " indirect " effects are of two fundamentally different types:

A. New technique over a wide range of industry, due to discoveries and improvements incidental to the development of atomic energy.

B. New research tools useful over an even wider field, due to the production in atomic energy reactions of " tracer " elements and radiation sources in relatively large quantities at low cost. This is perhaps the most important aid to scientific research since the invention of the microscope.

Under A we may note the following:—

1. New chemicals and chemical processes.

2. New methods of chemical, physical and isotopic analysis, and micro-analysis.
3. New vacuum techniques which provide high vacuum on a scale hitherto believed impracticable.
4. New valves, pumps and instruments.
5. New methods of monitoring and separating gases: diffusional separation of helium.
6. New methods of handling light gases such as helium, with special designs of valves, seals, glands and other details of flow technique.
7. New types of heat exchanger, smaller and more efficient.
8. New anti-corrosive materials and coatings.
9. New metallurgical techniques.
10. New technique and plant for oil-cracking and refining.

Amongst these items will be noticed at least two of special interest to the gas-turbine designer, namely improvements in helium production, helium engineering, and heat exchangers. It is precisely in these directions that we must look for the solution of major problems in the design of closed cycle gas turbines.

Turning to "tracer" technique, this is almost a new industry. It essentially depends on the introduction of a radio-active isotope into a material, a machine, or a process so that the behaviour of the atom can be observed and traced by its radiation. In suitable cases a non-radioactive stable isotope may also be used in a similar manner and its behaviour observed by means of a mass-spectrograph—an instrument which splits an atomic beam into its different isotopes.

If the development of atomic energy had produced nothing else, it is estimated that its cost would have been balanced in a few years by the gains in knowledge that the world can make with isotopes — in medicine, chemistry, industry and agriculture.

It is no exaggeration to say that already in the U.S.A. there is scarcely a scientific or industrial laboratory of any note which is not actively using the tracer technique. Literally thousands of shipments of radio-isotopes of over 100 different types have been and are being made from the U.S. Atomic Energy Commission's laboratories to bona-fide users all over the world. A condition is that the user shall supply to the Commission a report on the results obtained. Not unnaturally,

the U.S. authorities do not release isotopes for *industrial* laboratories outside the U.S.A., so that technicians elsewhere have the challenging knowledge that their friends in the U.S.A. have two or three years' start in this new field.

However, Canada and Great Britain have reactors at work fully capable of supplying all their domestic needs with a margin for export, whilst similar reactors will no doubt be starting in the near future in France, U.S.S.R. and other European countries.

The basic advantages of the "tracer" technique may be briefly summarized as follows:—

1. MEASUREMENT.—Regarded as a new type of sensitive balance, it permits weights to be measured with a sensitivity 100,000,000 times that of the most delicate balance available to the micro-analyst.

2. DETECTION.—Materials can be detected at a distance from themselves, without interfering with them or removing them. Indeed, they "radio" their own presence.

3. IDENTIFICATION.—The establishment of the type of radiation, beta or gamma, the energy and the period, fixes the identity of the emitting nucleus, and, therefore, of the chemical element to be traced.

There is inevitably a large and rapidly increasing literature on this fascinating technique, particularly in the medical and biological fields which have rightly had priority in supplies of isotopes. In metallurgy, the positive identification and location of minor constituents, which often profoundly affect the properties of metals and alloys, can be made by micro-radiography. This also applies to inclusions and the diffusion of one metal into another. On a larger scale specimens can actually be made to photograph themselves. This can be a powerful tool in detecting flaws and variations in homogeneity, as valuable to the engineer as to the metallurgist. In the same field, an important application is the use of gamma emitters of reasonably long life as substitutes for industrial and clinical X-ray machines. This has many advantages. The emitter, which is normally contained in a capsule, can be placed in a small cavity, for example in the human body or in a complicated machine or casting, and a gamma-ray photograph obtained. Apart from the low cost and convenience, there are many cases where the gamma source can be taken to the patient or to a defective part of

a machine, when it would be impossible or undesirable to take the patient or the machine to a powerful X-ray outfit.

To the mechanical engineer, it is fair to say that the two most vital problems in connection with machinery are the closely allied ones of wear and lubrication. Here the new tracer technique opens up a vast field not merely of research but of opportunity. It will, for example, enable the rate of wear in a bearing to be measured quite accurately and *continuously* to one-ten-millionth part of a gram. This could be done consecutively for all the bearings and moving parts subject to wear, in any machine, however complex.

The rate of wear can be observed immediately the machine is started up and over the period required to reach stable thermal and dynamical conditions. This is frequently the period of maximum rate of wear, because, amongst other factors, the lubrication system is not likely to be normal during that period. It will be possible to detect any change in the rate of wear due to vibration at the points in question.

Such methods of precision measurement under actual working conditions must normally be done by measuring the radio-activity of the lubricant due to the removal of sub-microscopic particles from the bearing surfaces. It follows that only one bearing or friction point can be observed at once, on any given lubrication circuit, and that it may be necessary to collect the lubricant in special sumps for the radio-activity measurements.

The normal procedure will be to add a small amount of a convenient radioisotope to the melt. The isotope selected should preferably, though not necessarily, have the following features:—

1. Its radiation should be of as high energy as possible so that the effects of extraneous influences and background are minimized.
2. It should have a reasonably long half-life, particularly if it is to be shipped some distance after activation, or if it is to be added to a melt which is to be followed by lengthy metallurgical and machining operations. For this a " half-life " measured in days is essential, and special air transport is frequently used for distances over 100 miles to reduce the time lost.
3. Its concentration in the metal should be sufficient to give signals of adequate strength within the limits of the instruments available.

Since the development of the cyclotron in the early thirties, radioisotopes had been produced and studied with such intensity that by 1940 some 360 of them could be tabulated. Most of the radioactive species produced in the pile can also be made in the cyclotron. A few species appear in fission, however, which cannot at present be made conveniently otherwise. This combined with continuing research with the cyclotron has brought the present list to about 450. The important contribution of the pile to availability is in the quantity aspect. The advantage factor thus introduced by the pile varies with the radioisotope under consideration. In some cases, a pile can supply a million times more of a radioactive species in the fission product range than a cyclotron. For many of the non-fission products, including several of the most important ones (e.g. carbon) the advantage factor is at present roughly a thousand.

The radioactive elements produced by fission range from zinc to the heavier rare earths. Of these, radio-elements in the region of barium and strontium are produced in much greater quantities than those in the regions of zinc or tin.

A second manner in which radioactive isotopes may be produced in the uranium pile depends upon the potential availability in the pile of more neutrons than are required to maintain the chain reaction. The surplus neutrons are removed by control rods which penetrate the pile to the desired degree and contain elements which absorb neutrons. A portion of the control rod function may be accepted by stable substances placed in the pile. These capture neutrons and in so doing become radioactive. The amounts produced in this manner vary with the excess neutrons potentially available, the power level of the pile, the amounts bombarded, the reactivity of the bombarded species, and the life expectancy of the product.

The powerful signals emitted by radioisotopes have been used to follow and measure a variety of industrially important substances otherwise untraceable, from the impurities in a batch of molten steel to the invisible coating on a wisp of thread. Manufacturers of steel, machinery, rubber, petrol, oil, plastics, rayon, chemicals, drugs and a rapidly growing list of other products are looking to these researches to bring better and more economical production.

The entire field of metallurgy is certain to be greatly influenced by tracer investigations already under way on the

structure, manufacture, alloying, durability, corrosion, and friction of metals, and the radioisotopes of more than a dozen elements are being used, including iron, calcium, carbon, sulphur, phosphorus, cobalt, silver, nickel, tungsten, copper and zinc.

The power of these new investigative tools makes them extremely versatile. A tiny quantity of radio-sulphur, for example, added to 25,000 pounds of mixed coal, enabled investigators to determine later what proportion of the sulphur impurities in the finished steel came from the coke and what proportion from the iron. Radiophosphorus, added to a molten batch of steel, joins with the phosphorus already present and thereafter, by its radiations, reveals the quantity of this impurity that still remains in the melt at various stages of processing. Radiocarbon, incorporated into iron during the coking process, provides investigators with a method of studying the diffusion of carbon in iron, a matter of great importance in the subsequent manufacture of steel. Radio-iron, used in friction experiments, has been able to reveal the transfer of less than one hundred billionth of an ounce of metal from one moving surface to another. Piston rings and other motor parts have been made radioactive for use in these latter studies.

Many of these metallurgical experiments take advantage of the technique of autoradiography, in which the precise distribution of the isotope-tagged material is photographed by the direct application of a film to the sample being analysed.

In the petroleum industry, the uses of isotopic tracers, both actual and potential, range from the surveying of the location and quantities of raw materials underground to the testing of the final product in operating engines. Radiocarbon, of course, is the most important isotope here; it is used to follow the changes through which crude oil goes in modern cracking processes and to study the process for manufacture of synthetic petrol from coal and natural gas. Radiocobalt is used to determine the rate of settling of rust inhibitors and other substances added to lubricating oil.

In the study of oil fields, the availability of radioisotopes of such elements as iodine, chlorine, cobalt and calcium is expected to result in new information about underground strata. Moreover, consideration is being given to tracer explorations of underground stores of fuel; radioisotopes in batches of oil or gas injected into a well, will be sought in

samples from neighbouring wells, and the resulting information about the underground routes in various parts of the field may make possible more efficient drilling procedures.

Similarly in other industries, tracer isotopes are throwing new light on fundamental problems. The way in which vulcanization and polymerization processes operate in the manufacture of rubber are being investigated with the radio-isotope of sulphur, the element that plays a primary but still largely mysterious role in these processes. The same isotope is solving a problem that has long made trouble in rayon manufacture, where sulphur must be added at one stage of the process and later removed because it lessens the strength and durability of the final product. Previously, it was impossible to determine at what stage of the process the sulphur had been eliminated; now a minute amount of radioisotope mixed with the sulphur in a test batch gives this information with extreme accuracy. Also in the rayon industry, the isotopic technique demonstrated its incredible delicacy when radiosodium succeeded in measuring accurately the coating on a tiny fraction of an inch of thread so fine that it weighs less than an ounce to the mile.

Turning to agriculture, more than half of the two billion people in to-day's world do not get enough to eat, and population is growing at the rate of about 20,000,000 a year. Food production is not increasing as fast as population. A prime need of mankind is a greater output of farm products. In bringing this about, man's oldest industry will be assisted by his newest: gains in agricultural production will result from the development of atomic energy.

True, research with isotopes has not as yet brought larger food yields; there has not been time. Before the war, isotopes were much too scarce and too expensive to be applied in any large way to farm problems. To-day, however, the radio-isotopes of a score of elements useful in plant and animal research, such as carbon, phosphorus, sulphur, calcium and potassium, are plentiful and inexpensive. Radio-phosphorus, the most widely used of these, is sold F.O.B. Oak Ridge at $1.10 per millicurie, and less than $100 worth is sufficient to supply an experiment station's programme of fertilizer research for an entire growing season. Stable isotopes of hydrogen, carbon, nitrogen and oxygen are also relatively plentiful; those of calcium, iron, zinc, molybdenum are available for extensive research for the first time.

Agricultural research with radioisotopes has raised many questions, suggesting a multitude of new projects. This multiplication of questions from season to season will inevitably continue for many years. After the second summer of isotope availability, more than 70 separate research projects are being conducted in 26 American laboratories and agricultural experiment stations.

The fundamental question of agriculture is how plants grow: how green leaves, in the process of photosynthesis, manufacture carbohydrates out of sunlight and the carbon dioxide in the air; how roots pick up minerals and organic matter from the soil; how these many substances are distributed in, and used by, the plant in its growth. The majority of such questions have gone unanswered because scientists had no means of observing the intricate processes and the tiny quantities of materials. But the tracer technique has changed this. To illustrate: using radioisotopes, plant scientists have been able to follow through the soil, into the roots, and to their final disposition in the plant, minerals such as zinc, copper and manganese, all of which are available to the plants in amounts of less than one ounce per acre.

Such research in the life processes of plants is carried on for its own sake. But some of the discoveries of the pure scientists in this field will eventually find use in the development of plant strains which yield more heavily or produce more exactly the fodder materials desired for better and faster growth of animals. For example, new knowledge about photosynthesis may enable scientists to develop plant strains that produce more energy-rich substances in their early stages of growth. This would be a boon to cattlemen.

Such work is certain to reveal how to get more plant growth —more food and feed—from the 15,000,000 tons of fertilizers upon which the American farmer spends half a billion dollars every year. Already, in field experiments conducted by the U.S. Department of Agriculture, and State agricultural experiment stations, and by the fertilizer industry in all parts of the U.S.A., radioisotopes are answering very specific questions: such questions as where, when and how plant foods are most effectively applied to different crops; what forms of fertilizer return the most in production; when and how the plant utilizes them; and how much expensive plant food is likely to go unused in to-day's fertilizing methods. For example, one study revealed that phosphorus is used by corn

mainly in the early stages of growth; another study found that potatoes use phosphorus throughout the growing season; a third that the fertility of the soil influences phosphorus up-take by cotton; and still another that with certain crops the manner of applying phosphorus is of primary importance. The U.S. Department of Agriculture has found that phosphorus, when placed very close to seed potatoes, seems to slow up the growth of the plant, probably because of injury to the young roots.

At least 12 current projects are aimed at better understanding of how plant diseases and pests develop and attack crops and, consequently, how they can best be defeated. Applications of radioactive iron, phosphorous, and sulphur to the investigation of chlorosis, tobacco leaf disease, fungus, and bacteriological problems, and the behaviour and control of harmful insects are in hand.

CHAPTER V

SOME ECONOMIC CONSEQUENCES OF ATOMIC ENERGY

FOR all current and foreseeable applications of atomic energy, uranium and its ores are the essential raw materials. Thorium is important as a source of fission material, but can only at present be used with uranium.

Pending international agreement on control, there is naturally great activity throughout the world in prospecting for uranium and thorium minerals.

Very highly concentrated deposits are well known, but in addition there are extensive medium-grade and low-grade deposits and it is estimated that the total workable content is sufficient to meet all predictable requirements for several hundred years, provided the whole of it can be used as fuel and not merely the active fraction.

Atomic energy is therefore potentially a most important supplement to the world's sources of natural fuel.

Uranium is known to be more abundant than mercury or silver, and about one thousand times more so than gold. The richest known deposits occur in Northern Canada and the Belgian Congo, but almost every European country has a small deposit, including the famous deposits at Joachimsthal, from which radium was first extracted. Quite recently it has been officially stated that some of the richest deposits in the world are in South Africa.

Indeed, the raw materials are far more plentiful than is commonly supposed and their allocation by mutual agreement to individual nations for legitimate *industrial* requirements should not present any more serious difficulties than other international problems.

When international problems of control have been successfully arranged, Canada and Great Britain, with their scientific, technical and industrial background, sharing with the U.S.A. the technical "know how" and with an urgent incentive to develop atomic energy for domestic reasons, should be in a good position to benefit from the export of highly specialized plant for the same purpose to the smaller countries throughout the world.

In addition to the actual export of plant, there would, in course of time, be valuable "invisible" exports, because with

plant must go highly skilled technicians in all categories to supervise plant layout, installation and operation; in addition, other invisible exports of value might develop, such as finance and insurance, both of which would call for specialized knowledge and experience of the factors and risks involved.

The following list gives some of the major items of export which the U.S.A., Great Britain and Canada would be in a position to supply to other countries for atomic energy purposes.

Reactors.
Reactor shielding.
Controlling gear and instruments.
Heat exchangers.
Special steam and gas plant.
Gas turbines.
Auxiliary plant.
High-purity U. and Th. fissionable metal.
Beryllium graphite and heavy water for moderators.
Radioisotopes.
Special laboratory equipment.

The economic consequences of atomic energy are, of course, mainly governed by the extent to which it can be used for generating electricity.

It is well known that the cost of electrical power as delivered at the consumers' meter is, to a large extent, controlled by items other than the actual cost of the fuel used at the power station. The following figures from an authoritative U.S.A. source give the 1933 analysis:—

	Cents per kW-hr.
Generating cost including fuel	0.47
Fixed charges (interest, depreciation, etc.) on generating station	0.78
Transmission and substation operation ...	0.16
Fixed charges on transmission and substation equipment	0.33
Operation cost of distribution lines from substation to consumer	0.29
Fixed charges on distribution equipment ...	1.45
Administration, book-keeping, reading meters, service calls, etc.	1.80
Total cost at consumers' meters	5.28

Note that the gross cost of fuel is less than 10 per cent. of the total, and therefore atomic energy as a national source of electrical power for countries such as the U.S.A., Canada and the U.S.S.R. does not necessarily offer rich rewards.

In countries such as Great Britain, however, fuel costs represent a much larger percentage of the total, and very much larger coal percentages are used for domestic and industrial heating, whilst oil is imported for similar purposes, and also for power.

Thus, although it is important that atomic energy may be obtainable at a somewhat lower all-in cost than coal, that possibility alone is not the vital one, but rather that it can be used in lieu of coal and thereby release valuable raw materials for exports or alternatively conserve resources of hydro-carbons, which represent precious national assets.

The British Ministry of Fuel and Power give the following official analysis of the coal consumption of Great Britain in 1946:—

	1946 *Million tons*
Gas-works	22.7
Electricity	26.2
Waterworks	0.4
Railways	15.0
Coke ovens	20.0
Collieries	10.6
Iron and steel	9.6
Engineering	3.7
Other industry	29.6
Non-industrial establishments	3.2
Domestic (i) House coal	28.7
(ii) Anthracite and boiler fuel ...	2.4
Miners' coal	4.8
Coastwise bunkers	1.0
Miscellaneous	4.8
Total (Great Britain	182.7
Shipments to Ireland (Northern)	2.5
Overseas shipments and bunkers	9.7
	12.2
Total consumption and shipments ...	194.9

It is obvious that atomic energy cannot release one hundred and ninety-four million tons of coal for export, but within a reasonable period one might expect savings broadly as indicated below:—

	Percentage substitution of atomic energy	*Saving of coal Million tons*
Gas	50	11.3
Electricity	90	23.6
Waterworks	—	—
Railways	—	—
Coke ovens	—	—
Collieries	—	—
Iron and steel, Engineering, Other industry ...	10	4.3
Non-industrial establishments	—	—
Domestic	50	14.3
Miners' coal	—	—
Coastwise bunkers ...	—	—
Miscellaneous	—	—
Total		53.5

Estimated potential saving of coal: 53.5 million tons.

On this basis it appears that the conversion of electricity undertakings to burn atomic fuel on a large scale in lieu of coal would not be likely to achieve more than a saving of about 25 per cent. of internal coal consumption. If the equivalent coal is exported there would obviously be no reduction whatsoever in the labour force required for coal mining. This conclusion is opposed to that of other investigators, who have assumed that atomic energy implies the end of occupations such as coal mining.

On the other hand over 50,000,000 tons per annum of coal would be shipped abroad in lieu of being transported by internal railways, roads, canals and coastwise colliers, and there would be a valuable transfer of non-productive labour from the transport industry to engineering and other productive industries.

Fortunately, neither Great Britain nor any other nation need incur the staggering financial cost undertaken by the

U.S.A. in the first three years of the development, that is between 1942 and 1945. This effort was justified by the belief inspired and encouraged by Britain and Canada, that small quantities of nuclear fuel would make possible an explosive of unprecedented violence, and that the course of the war might be decided by whichever side obtained this weapon first. As an indication and record of the cost and labour involved, the following figures deserve both attention and reflection:—

Data on Cost and Size of Atomic Energy Projects in the U.S.A. in 1945

A. *General* (including construction and other activities).

	$
Gross expenditure on June 30, 1945 ...	1,950,000,000
Construction workers at peak	125,000
Operating personnel on August 6, 1945	65,000

B. *Major Construction Costs and Indications of Size of Installations.*

Installation	Expenditure in millions of dollars	Construction workers at peak	Size of installation
Gaseous diffusion process U.235	545	25,000	Four-storey building, half-mile across, covering 60 acres
Electro-magnetic separation process U.235	350	13,200	175 separate buildings, including 9 major processing structures
Thermal diffusion process U.235	10.5	.—	Main building 525 by 82 ft. by 75 ft. high
Hanford Pu.239	350	45 000	600-square-mile site. Three huge reactors and chemical separation plants. 780,000 cu. yds. of concrete
Experimental reactor at Clinton	12	3,247	Designed for 1,000-kilowatt capacity

The above table includes the cost of four distinct processes for the production of concentrated nuclear fuel, and all four were put in hand as major industrial plants with little more than laboratory technique as guidance. Over three years have since elapsed and it is difficult to judge which method is most successful, and most likely to be selected for further development. A fairly sound pointer is given, however, by the fact that the Hanford plant is at present being reorganized on a permanent basis, indicating that a plant manufacturing plutonium is probably more economical to operate than isotope separating plant.

Writing off the whole of the research and development costs, how will atomic energy compare with other sources of power on a strictly commercial basis. There is at present only one nation—the U.S.A.—with sufficient full-scale data to approach this evaluation with any degree of confidence. Two separate groups of workers have been employed on this important task and arrived, independently, at the conclusion that the net all-in cost of electricity per kilowatt hour, delivered to the consumer, would be about the same for nuclear fuel as for coal, and definitely higher than for a favourably situated hydro-electric plant. These conclusions are not surprising in view of the fixed charges on electricity production which are quite independent of the type of fuel, and the results underline the statement that the real importance of atomic energy lies not so much in whether it may or may not be cheaper, but in its use as a means to conserve the world's resources of natural fuels.

Let us consider some more figures: before the outbreak of World War Two, the world production of uranium was approximately 1,000 tons per annum. The U.235 content of this is about 7 tons per annum. This could provide effectively about two million kilowatts of electric power per annum, which is the best we can expect with present technique. If we could burn the U.238 as well as the U.235, we could provide two hundred million kilowatts per annum, without even taking into account the use of thorium, which also can only be burnt in the presence of U.235. This reveals in a striking manner the enormous gap between what we can do now with atomic energy, and what we could do if we knew how! In the meantime, for every 1,000 tons of uranium used in a U.235 diffusion plant or in a Pu.239 reactor, about 900 tons of this precious metal are sterilized from the power point of view.

This is a factor in the current situation which has not been sufficiently stressed. It is no exaggeration to say that if all the U.235 were extracted from the uranium in the earth's crust, and dissipated, the *rest* of the uranium and the *whole* of the thorium would be quite worthless except for relatively unimportant chemical and metallurgical purposes. The moral is that uranium should not be used on a large scale for power production until the problems on which atomic scientists are at present engaged have been solved, not merely in the laboratory but in a prototype industrial plant.

A few hundred years is a relatively short period in the history of a nation, and at a time when many people would be happy to feel that fuel supplies were safe for at least 12 months ahead, it may seem inappropriate to draw attention to the appalling rate at which our modern civilization is using up irreplaceable fuels such as coal and oil. This may be of no immediate concern to us but it surely will be to our successors in 100 years' time. There is even a limit to foreseeable sources of raw materials for atomic energy—this limit is of about the same order as for coal and oil. It does not, therefore, need a vivid imagination to suggest that unless the use of fission fuel is controlled, the industrial nations on this planet will eventually be those with large hydro-electric plants or those with vast areas of afforestation.

CHAPTER VI

SHIP PROPULSION BY ATOMIC ENERGY

THE British Admiralty and the U.S. Navy Department are naturally profoundly interested in the consequences of atomic energy, both as a weapon and as a potential means of propulsion. From the mercantile point of view it has already been noted that shipping interests are strongly represented on the U.S. Atomic Energy Committees whilst the British Shipbuilding Research Association has recently stated that the applications of atomic energy for ship propulsion are under consideration with the Ministry of Supply. It will be seen later that a great deal depends on the simultaneous development of the high-powered closed cycle gas turbine, and it is significant to note that a contract has recently been placed for a 15,000-kW plant of this type by the North of Scotland Electricity Board, to be used in due course in connection with atomic energy.

In view of the fact that a large passenger ship or battleship may take five or six years to build, from drawing board to sea trials, it is essential that the problems involved in atomic energy propulsion should be studied simultaneously and progressively with the corresponding problems of land power stations.

A standard 20,000-kW unit is suggested as a reasonable compromise between a very large unit which could only be used, if at all, on very large ships, and a relatively small unit, which would embody the inherent disadvantages of an atomic plant without adequate compensations. Again, an atomic reactor designed for a maximum power level of 20,000 kW can be operated at any *lower* power level without reducing the efficiency of the reactor and without reducing the temperature and pressure of the steam or gas supplied to the prime movers.

Such a plant could also be made fairly compact and would be designed so that the reactor unit complete with shielding could be lifted bodily from the reactor room and put ashore at a central service station for overhaul, whilst a new reactor would be lowered into position. It is reasonable to assume that this would not be necessary more than at, say, five-year intervals and, in any case, it is obvious that occasional access

to all parts of the ship's structure must be provided for. If, therefore, atomic energy is employed on mercantile vessels, this indicates in general terms the probable trend and limits of practical application.

It follows that the complete propulsion system of the ship could be in six distinct sections, as follows:—

1. REACTOR UNIT.—Complete with fuel, heat-extraction system, instruments and heavy shielding. All connections to the reactor to have detachable couplings *outside* the shielding. Removable en bloc.
2. PRIMARY HEAT CIRCUIT AND CONTROL STATION.—This circulates the coolant on a closed circuit from the reactor through the heat exchanger and back to the reactor. This section with auxiliary plant will also require shielding, but less heavy than the reactor shielding.
3. SECONDARY HEAT CIRCUIT.—This supplies steam or gas at the designed working temperature and pressure to the prime movers. The secondary circuit may be either closed or open, as it will not be appreciably radioactive—certainly well below accepted degrees of tolerance. No shielding will be needed, for reasons which are explained below.
4. PRIME MOVERS.—These may be direct or geared turbines, turbo-generators or gas turbines.
5. SHAFTING AND PROPELLERS.—Normal.
6. AUXILIARIES.—Normal.

The compartment occupied by the reactor and the primary heat circuit will both demand ventilation arrangements of a very high order. In this respect they will simply follow corresponding practice for stationary atomic plant. Some further comment on the radio-active effects is here appropriate.

Inside the reactor the activity consists of:

Neutrons.
Gamma Rays.
Fission Products—beta and gamma active.

With a well-designed reactor and shielding, the neutron escape should be negligible. A neutron atmosphere has no chemical affinities, and no normal physical properties. For example, a high-speed gas coolant flowing through a reactor would not carry any free neutrons away with it. Thus the neutrons may be regarded as entirely confined to the reactor space. On the other hand the irradiation of the coolant by the neutron flux will cause induced beta activity in most cases

and this will be carried round the closed primary heat circuit. Beta-active fission products may also be carried by the coolant unless prevented by sheathing the uranium. The intense gamma radiation of the reactor is, of course, electromagnetic, similar to hard X-rays, and, provided the shielding is adequate, all hard gamma radiation is confined to the reactor compartment.

Consider now the heat exchanger, the function of which is to bring the primary and secondary heat circuits as close together as possible. It will be seen that the only radiation in the heat exchanger will be beta and gamma radiation in the primary circuit, and however intense this may be it cannot induce beta or gamma radiation either in the material of the heat exchanger or in the fluid of the secondary circuit. From the physiological point of view, it is essential that personnel should not be exposed to radiation. This can be safeguarded by adequate shielding of the primary circuit and heat exchanger, and by special ventilation. Outside the heat exchanger compartment, the conditions would be entirely normal, that is in the main and auxiliary engine rooms.

In a recent paper (" The Royal Navy and Nuclear Power," Daniel, Inst. of Naval Architects, March, 1948) it is suggested that " a possible solution to the coolant problems for installations where it is not essential to keep the ship closed up all the while might be to use air, the air being drawn into the reactor from the weather deck, circulated either to a heat exchanger or actually used as the driving fluid itself in a turbine and exhausted at high velocity into the air above the ship." Those on board any other ships following in the air wake of such a vessel, even several miles astern, might suffer severe consequences. In harbour or any busy waterway, the conditions would be intolerable. Thus without being unduly dogmatic, it may be said that there are the strongest possible reasons why the primary circuit should be a closed one in any mobile installation, so that all radio-active effects are under adequate control. Even so, the necessity for super-ventilation of the active compartments should not be dispensed with as a precaution against small undiscovered leakages.

A means of keeping the gaseous fission products under control would be to reduce to the absolute minimum the free space available for gas accumulation in the reactor and shielding. The gas concentration could then be extracted by

a suction pump and stored at high pressure in ordinary gas cylinders with suitable shielding, in a special compartment for eventual disposal. The radiation at this stage will be such that a few inches of lead shielding would suffice. At least in this way one would know where the fission products were. It would surely be a severe blow to atomic ship propulsion if installations were sent to sea emitting a highly radio-active exhaust, particularly if perfectly safe conditions can be obtained by a closed circuit.

Before leaving the subject of radiation, there is one more important factor to keep in mind, namely, the tendency for the neutron flux, gamma and beta rays to produce ionization in the coolant fluid, with attendant electrolytic corrosion problems. Even water/steam in the secondary circuit would tend to become ionized by the radiation in the primary circuit where it passes through the heat exchanger. From this and other points of view, the ideal is certainly to have helium as the fluid for *both* circuits. Helium does not become radio-active under neutron bombardment and so is not a carrier of activity except as radiation from fission products, it is chemically inert and its thermal properties excellent. It has already been seriously proposed for the A.K. closed-cycle

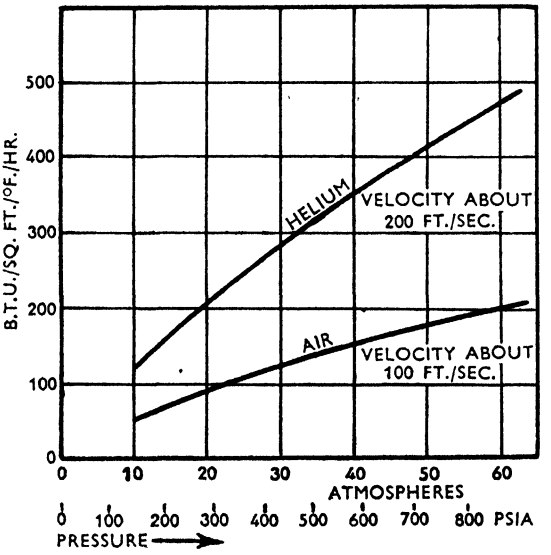


Fig. 2.—Comparison of heat transfer for air and helium in tubes of 1.2-in. diameter. Equal relative pressure drop.

gas turbine, where it offers unusually high overall efficiency.

Generically, a closed cycle gas turbine may be defined as one in which the gas is first heated *indirectly* by the fuel, then passed through the turbine surrendering its heat in the form of useful work, then compressed, reheated and readmitted to the turbine, and so on continuously. It may well be that the atomic age will also bring with it the age of helium engineering. No doubt helium production will be able to meet the potential demand.

Consider the comparison between helium and air shown in the diagram. (Fig. 2.)

The effect of the striking difference between air and helium on the heat exchanger characteristics may be summarized as follows:—

Helium Heat Exchanger. Differential Ratios for Air and Helium for Equal Output, Pressure and Temperature

	Air	Helium
Specific heat	1	10
Coefficient of heat transmission	1	2.56
Number of tubes	1	0.56
Length of tubes	1	0.70
Surface area of tubes	1	0.30

This illustrates very forcibly the rewards obtainable by using helium. It not merely gives a reduction in size. A heat exchanger for a 20,000-kW power plant is a very expensive unit, comparable in size with a water-tube boiler of the same capacity, and with a capital cost of the same order, this being largely governed by number and size of tubes. It follows that a very substantial saving in first cost of heat exchanger is obtained by using helium, and this can immediately be set off against the first cost and make-up cost of the gas.

This, however, is only half the story. Turning our attention from the heat exchanger to the turbine, comparisons based on calculations by Ackeret indicate that an improvement in thermal efficiency in the ratio of about 1:1.35 can be confidently expected as between air and helium.

It is reasonable, therefore, to assume that there will be a

reduction of the order of 30 per cent. in the size, weight and cost of the gas turbine, using helium. On a 20,000-kW turbine this is obviously a substantial saving in capital cost.

This leads to the possibility that helium engineering will develop side by side with atomic energy to their mutual advantage. Indeed, unless the above analysis of the position is at fault, the conclusions which emerge may be summarized in the form of an ideal power unit with the following main features.

REACTOR:	"Medium-Fast" Type. Initial charge—concentrated 233, 235 or 239 diluted with natural uranium. Continuous make-up feed of natural uranium and/or thorium at the rate of .01 lb. per hour per 1,000 b.h.p.
PRIMARY CIRCUIT:	Helium—closed.
SECONDARY CIRCUIT:	Helium—closed. Gas-Turbine—Electric. Closed Cycle. Temperature = 1,000 degrees F. Pressure = 1,000 lb. per sq. in.

The ideal standard unit as broadly specified above would be suitable for either land or marine service, and in order to achieve it the chief technical problems to solve are (a) Continuous natural fuel feed for the reactor; (b) Helium technique.

Assuming that such standard units become available for marine propulsion, what would be the result?

It will be seen that the scheme implies electric drive for the propellers. There would, of necessity, be an auxiliary engine-room for which standard Diesel-electric units would be suitable. Apart from the reactor and its controls, there would be nothing unduly novel in the arrangement. The weight and space would be about the same as for a steam-turbine installation, that is, rather more than for direct Diesel or Diesel-electric. The weight of a reactor unit of 20,000 b.h.p. would be of the order of 200 tons complete with shielding and the section of the primary circuit which is contained by the reactor and shielding. The casings and deck openings over the reactor must permit of its being bodily removed without undue disturbance.

Another factor to be considered is the effect of atomic energy on the maximum speed and power.

It is not suggested that a ship such as the "Queen

Elizabeth " might, with the aid of atomic energy, double its present speed. Propulsion by atomic energy would not alter the fact that this would require more than eight times the present power—say 1,600,000 b.h.p. in lieu of 200,000 b.h.p.!

As screw propellers would be essential in our present state of knowledge, it may be stated categorically that such a prediction is not likely to be realized unless some other epoch-making change were made, such as the use of a hydro-plane type of hull.

However, with the normal " displacement " type of hull, it would be practicable with atomic energy, to aim at a moderate increase in speed of, say, 20 per cent., which would almost represent the limit the present propeller-blade material would stand without serious damage by water hammer. This would correspond to an increase in power of over 60 per cent. and would involve larger propelling machinery, or an increase in r.p.m.

For most ocean services, the maximum dimensions in terms of length, breadth and draught, are determined by the facilities at the terminal ports and also by the limits imposed by dry docks. The maximum speed is essentially a matter of compromise between a variety of considerations such as capital cost, volume of traffic, fuel consumption and comfort of passengers.

At present any material increase in *size* would not be practicable and, as already pointed out, any marked increase in speed, even with atomic fuel, would involve serious engineering difficulties and would not necessarily be desirable.

To sum up, the probable effect on ship propulsion would be disappointingly unspectacular but the saving in weight and cost of fuel, release of space occupied by bunkers, coupled with the almost unlimited range, would have a spectacular effect on ship economics. At present there are too many uncertain factors and too little established data, to make a useful evaluation.

From the naval point of view, Daniels, in the paper referred to above, summarizes his conclusions as follows:

Conclusions	**Commentary**
Nuclear reactors provide an ample source of energy in the form of heat, and are capable of producing power continuously for long periods.	Agreed.

Conclusions	Commentary
They require no fuel or contact with the air, save in cases where air is used as the coolant, and perhaps, the working fluid.	Agreed. But as a closed circuit is essential to control radio-activity afloat, more efficient coolants than air should be used.
There is little possibility at present of reducing the total weight and space requirements for machinery and fuel; it is probable that the total length of machinery spaces will go up, due to the fact that the reactor cannot be stowed away as neatly and conveniently as the oil fuel it replaces.	Agreed. But the difference, if any, in gross space is probably negligible.
The upper limit to power developed in a given layout will probably be governed by the heat-exchanger/boiler capacity for producing steam.	Agreed. And also by the amount of hydrodynamic damage the hull and propellers will accept.
The difficulties of maintenance of the pile, and especially the heat exchangers and associated ship's structure, are formidable in view of the radioactivity in and around these spaces.	All moving parts in the primary circuit should, as far as possible, be in duplicate. The reactor unit should be removable en bloc. The remainder of the primary circuit can then have the coolant evacuated, the system decontaminated as far as possible with clean gas or liquid, and then allowed to "cool."
When refitting or damaged, the vessel is liable to be out of service for a considerable period until the radioactivity dies down to a safe level to permit work to take place in the vicinity.	Not necessarily. See above. Using this technique, residual radio-activity should be reduced to the tolerance limit in a few days.

Conclusions	Commentary
The reactor, and hence the whole propulsion system of the ship, is vulnerable to enemy attack. If more than one reactor is fitted in a ship, economy of weight of shielding will probably demand that they be placed in the same or adjacent compartments.	The reactor being surrounded on all sides, also top and bottom, by five or six feet of solid concrete, should be the least vulnerable part of the ship. Surely the main engine-room is likely to be more vulnerable.
The atomic reactor is well suited to submarine propulsion, developing full power under all conditions, and quite independent of whether the submarine is on the surface or not.	Agreed. With a standard reactor unit, removable for recharging, so dispensing with the complication of loading and unloading the uranium at sea. This would permit of a much more compact and convenient unit.

Daniels, not unnaturally, considers that atomic energy is so ideal for submarine propulsion that such vessels should in fact have priority when supplies of uranium are available. That is an issue which will no doubt be hotly disputed, and, indeed, the whole course of ship propulsion by atomic energy must be left for the march of time to decide.[1]

[1] In December, 1948, it was announced in Washington that an atomic power unit suitable for a warship had been ordered from the Westinghouse Electrical Corporation, to specifications prepared by the U.S. Navy Department, which has a highly efficient team working on the practical applications of atomic energy to ship propulsion.

CHAPTER VII

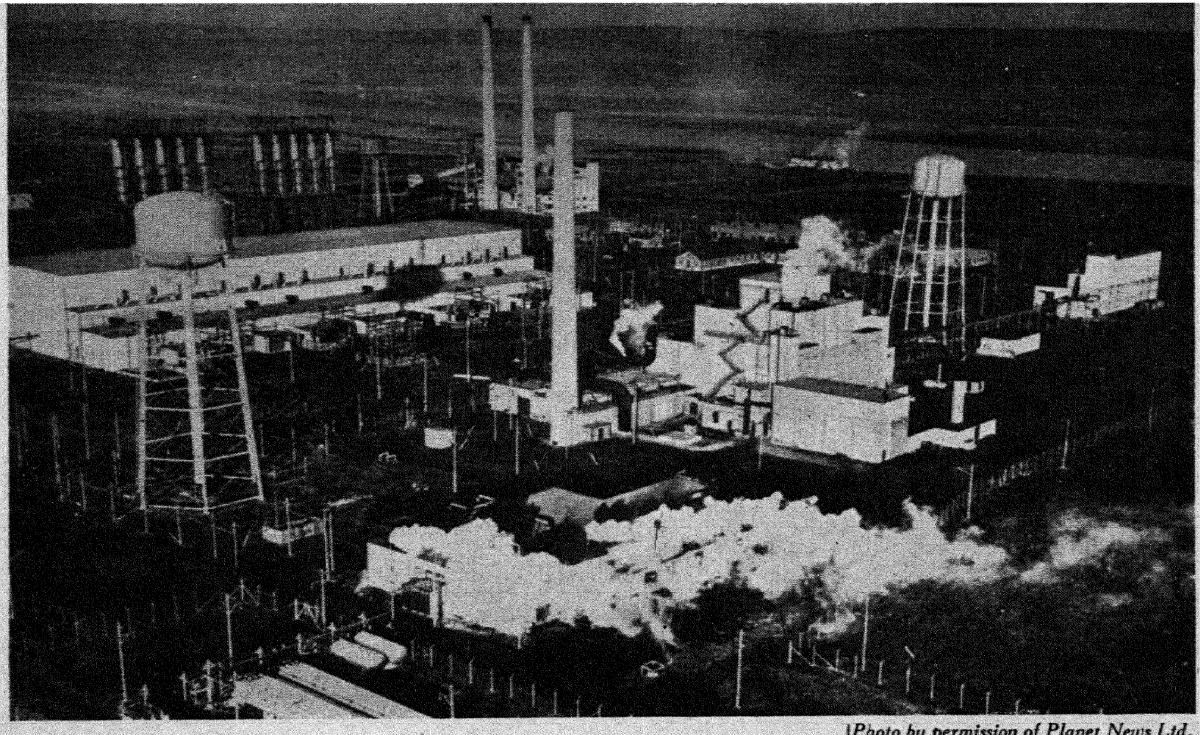
SURVEY OF ATOMIC ENERGY DEVELOPMENTS

A.—In the U.S.A.

A VAST monolith carved in space and time marks the contribution of the United States of America to the development of atomic energy. It has indeed many of the characteristics inherent in the American way of life: a genius for grasping an idea and making it work, imagination, enthusiasm, drive, scientific ability, technical skill, and the great industrial potential required to translate a laboratory experiment into a world-force. History will record that when peace came after the Second World War, the United States, with the natural generosity characteristic of a great nation, was fully prepared to share with the world the benefits of her advanced knowledge of a new power over Nature. Immediately, the release was ordered in Washington of the famous Smyth Report. Although an official publication, this may rightly be regarded as the most magnificent and unselfish "breach of security" in the history of any nation. There is certainly no historical parallel to this document, and no other nation has made similar revelations. It may be argued by some that no vital secrets were disclosed in the Smyth Report, but nuclear science is still a jig-saw puzzle with many pieces missing, and even the *deliberate* omissions from the Report were significant.

President Roosevelt, advised by his service chiefs, took the ultimate decisions as to the use of atomic energy as a method of waging war, and this is not the place to discuss the validity of those decisions, except to remark that one can understand the view that the discovery of the atom bomb should have meant not merely the end of one war, but the end of all wars: the end, even, of the *fear* of war.

In the course of American development of atomic energy many great leaders of science took part, but here only a few names will be mentioned: Einstein, with his supreme mathematical insight; Bohr, who collaborated with Wheeler, discovered vital clues to the fission process; Fermi, who worked with Zinn and others to make the first chain reactor;



[*Photo by permission of Planet News Ltd.*

A Plutonium Production Plant at Hanford.

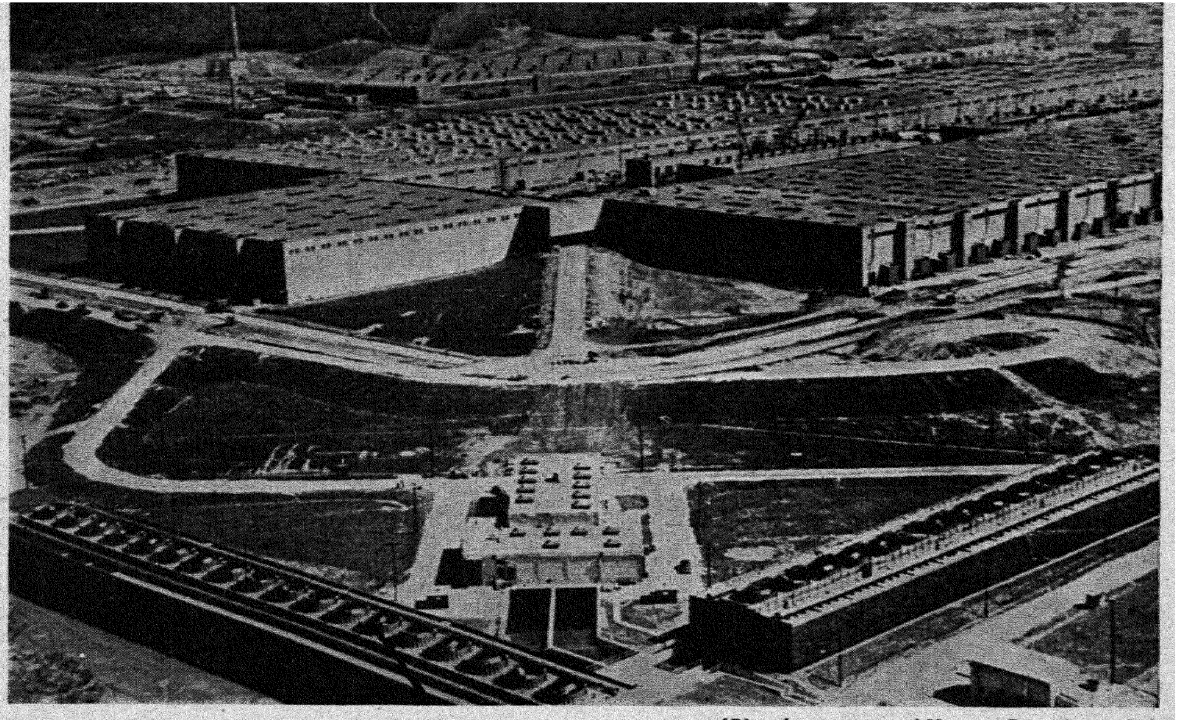
Breit and Wigner, who helped to create scientific bricks without straw; Oppenheimer, who lead a brilliant team with brilliance; Groves, who carried the burden of administration with unique ability; and finally Smyth, who not merely kept a record but brought his own distinguished contributions to the common pool.

These great achievements would still have remained on a somewhat academic level without the vast technical resources of the many great American industrial concerns which took part in this adventure, and in particular du Pont, Monsanto, Carbon and Carbide Chemicals, and General Electric. Work of this nature frequently has serious embarrassments and repercussions for leaders of "private enterprise," particularly in peace-time when it is apt to be pilloried as "war-mongering." In Great Britain, firms such as Imperial Chemical Industries and Vickers have been similar targets. Nevertheless it is clearly essential that the natural leaders of industry should lead this development, and in a recent statement the chairman of the U.S. Atomic Energy Commission, David E. Lilienthal, wrote:—

> "A continuing monopoly approach to the development of atomic energy would slow and dry up the effort. So Congress directed the Atomic Energy Commission to find safe ways to move away from government monopoly, a directive with which the Commission heartily agrees. The Commission should move away from tight government monopoly as fast as it can, consistent with security. . . . The development of America's technology has always been through the widest possible dissemination of information, through the cross-fertilization of ideas . . . . The need for secrecy presents one of the toughest hurdles in the path of rapid development of the new atomic technology. . . . An indiscriminate hush-hush attitude of choking back any and all interchange of knowledge may do inestimable damage to our own country's progress."

It is significant that in less than four years after the discovery of nuclear fission the U.S.A. had an atomic reactor at work at Chicago, and three years later the Hanford plants were manufacturing plutonium on a mass production basis, the plants being operated by the du Pont Company under contract from the U.S. Army.

In 1946 the responsibility for the development of atomic



[*Photo by permission of Keystone Press Agency Ltd.*

Uranium 235 Production Plant at Oakridge.

energy in the U.S.A. was transferred from the military to the civil authorities and two new contracts were then issued:—

1. General Electric Company.
2. Monsanto Chemical Company.

The General Electric Company are now operating and expanding the huge Hanford Plutonium production establishment, and also have a contract for a plant under construction on a new site near Schenectady, New York, where several different designs of power pile are being prepared, both for land and marine purposes.

The Monsanto Company commenced building an atomic power station at Oak Ridge, Tennessee. This plant is intended to provide heat energy for steam-driven turbo-generators, operating at conventional power station temperatures ranging from 650 degrees F. to 940 degrees F. As this is essentially a prototype commercial unit, special attention has been given in the design and construction to ensure a heat source of long life and great reliability, but its completion probably awaits the solution of outstanding problems.

Leading industrial concerns lent personnel for this, and the scope and importance of the project may be assessed by the following list of firms who released groups of engineers and scientists for research and development under the general leadership of Monsanto:—

Allis-Chalmers Co., Milwaukee, Wisconsin.
Babcock and Wilcox Co. New York, New York.
Bureau of Ships, U.S. Navy, Washington.
Frederick Flader Inc., Tonawanda, New York.
General Electric Co., Schenectady, New York.
National Advisory Committee of Aeronautics, Washington.
Northrop Aircraft Corporation, Hawthorne, California.
Tennessee Valley Authority, Knoxville, Tennessee.
Purdue University, Lafayette, Indiana.
Wright Aeronautical Corporation, Woodbridge, New Jersey.
University of Wisconsin, Madison, Wisconsin.
University of Chicago, Chicago, Illinois.
U.S. Public Utilities Companies.
Combustion Engineering Company, New York City.
Commonwealth Edison Co., New York City.
Foster Wheeler Corporation, New York City.

The operation of the Oakridge Establishment was continued by Montsanto until the end of 1947, when, for reasons

of policy the company decided not to seek renewal of the contract, which was taken over, from January 1, 1948, by the Carbon and Carbide Chemicals Corporation.

At Hanford, the entire plant is being re-organized by General Electric on an extremely ambitious and far-reaching scale, including a new reactor for plutonium production. Contracts are in hand for new and enlarged roads and railways, including two major bridges over the Jakima River, with big extensions in housing, electrical power, telephones, lighting and other facilities. The permanent housing scheme alone is a 14 million dollar effort. Similar work is in hand at the experimental stations at Los Alamos, Oak Ridge, Brookhaven, Argonne and Knolls, Schenectady. This does not include the nation-wide research on fundamentals with the aid of cyclotrons, synchrotrons, betatrons, and van de Graf's, together with all the other weapons of nuclear research.

The tables on pages 78 and 79 give a tentative list of U.S. reactors completed or proposed.

Internal control of Atomic Energy is vested in the United States Atomic Energy Commission.

HEAD OFFICE: Washington 25, D.C.

CHAIRMAN: David E. Lilienthal.

MEMBERS: Robert F. Backer.
Sumner T. Pike.
Lewis L. Strauss.
William W. Waymack.

DIRECTOR OF RESEARCH:
Dr. James B. Fisk.

GENERAL MANAGER: Carrol L. Wilson.

GENERAL ADVISORY COMMITTEE:
Dr. J. Robert Oppenheimer,
Director of the Institute for Advanced Study, Princetown, N.J. (Chairman.)
Dr. James B. Conant,
President of Harvard University.

U.S.A. Reactors

	Location	Type	Fuel	Purpose
1	Chicago	Low temperature, graphite, air-cooled, 200 watts	Uranium and uranium oxide	First experimental chain reactor
1A	Clinton	Ditto, 1,000 kW.	Uranium	Second ditto
2 3 4	Hanford	Low temperature, graphite, water-cooled, large capacity	Uranium (aluminium casings)	Plutonium production
5	— (Smyth Report)	Very low temperature, no cooling	U 235 in liquid solution	Experimental
6	— (Smyth Report)	Low temperature, air-cooled ?	Uranium mixed with hydrogenous material	Experimental
7	Los Alamos	" Fast " reactor	Plutonium	Experimental " hot-water boiler "
8	Los Alamos	Ditto ?	—	—

U.S.A. Reactors—continued

	Location	Type	Fuel	Purpose
9	Argonne	Low temperature, heavy water	Uranium	Experimental and isotope production
10	Oakridge	Low temperature	Uranium	Ditto
11	Oakridge (design stage)	High temperature, high neutron flux	Uranium (enriched ?)	General research on power production
12	Argonne (design stage)	High temperature	Uranium	Production of useful power
13	Knolls-Schenectady (design stage)	High temperature	Uranium	Ditto (different design)
14	Brookhaven (design stage)	Medium temperature, graphite, air-cooled	Uranium	Special experimental
15	Hanford	Similar to 2, 3, 4, with modifications	Uranium	Plutonium production

Dr. Lee A. Du Bridge,
President of California Institute of Technology.

Dr. Enrico Fermi,
Professor of Physics, Institute for Nuclear Studies, University of Chicago.

Dr. I. I. Rabi,
Chairman of the Department of Physics, Columbia University.

Hartley Rowe,
Vice-president and Chief Engineer, United Fruit Company.

Dr. Glenn T. Seaborg,
Professor of Chemistry, University of California.

Dr. Cyril S. Smith,
Director of the Institute for the Study of Metals, University of Chicago.

Hood Worthington,
E. I. du Pont de Nemours and Co., Inc.

ADVISORY COMMITTEE ON ISOTOPE DISTRIBUTION:

Dr. G. Falla,
Columbia Unversity Medical School. (Chairman.)

Dr. H. A. Barker,
University of California.

Dr. Robley D. Evans,
Massachusetts Institute of Technology.

Dr. Hymer L. Friedell,
Lakeside Hospital, Western Reserve University.

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University of California.

Dr. Joseph W. Kennedy,
Washington University, St. Louis.

Dr. Robert F. Mehl,
Carnegie Institute of Technology.

Dr. Paul C. Aebersold,
Chief Isotopes Division, A.E.C., Chicago.

Dr. Austin M. Brues,
Argonne National Laboratory, A.E.C., Chicago.

Dr. A. H. Holland, Jnr.,
A.E.C., Oak Ridge.

Dr. L. N. Nims,
Brookhaven National Laboratory, A.E.C., Long Island.

BOARD OF INDUSTRIAL CONSULTANTS:

James W. Parker, president and general manager of the Detroit Edison Co., is to be Chairman of the group. Other members include: O. E. Buckley, president, Bell Telephone Laboratories, New York, N.Y; Donald Carpenter, vice-president, Remington Arms Co., Bridgeport, Conn.; Gustav Egloff, director of research, Universal Oil Co., Chicago, Ill.; Paul Foote, executive vice-president, Gulf Research and Development Co., Pittsburgh, Pa.; Robert G. Wilson, chairman of the board, Standard Oil Co., of Indiana, Chicago, Ill.; and Walker Cisler, chief engineer of power plant, Detroit Edison Co., who will serve as executive secretary to the group.

BOARD OF MEDICAL AND BIOLOGICAL CONSULTANTS:

A medical board of review to advise the U.S. Atomic Energy Commission on nuclear research in the medical and biological fields has been set up. The following have been appointed to this board: Dr. Robert P. Loeb (Chief Division of Medicine, Presbyterian Hospital, New York), Chairman; Dr. Detley W. Bronk (Chief Radiologist, University Hospital, Philadelphia); Dr. Wallace O. Fenn (Professor of Biology, University of Rochester Medical School, Rochester, N.Y.); Dr. Herbert S. Gasser (Physiologist, Rockefeller Institute for Medical Research, New York); Dr. Ernest W. Goodpasture (Vanderbilt University School of Medicine, Nashville, Tenn.); Dr. Alan Gregg (Director for Medical Sciences, Rockefeller Foundation, New York); and Dr. A. Baird Hastings (Harvard Medical School, Cambridge, Mass.).

U.S. ATOMIC ENERGY COMMISSION:

Development and Research Establishments.	*Operating Contractors.*
Oak Ridge National Laboratory, Oak Ridge, Tenn.	Carbide and Carbon Chemical Corporation.
Los Alamos Scientific Laboratory, Los Alamos, New Mexico.	University of California.
Brookhaven National Laboratory, Upton, L.I. N.Y.	Associated Universities Inc.
Argonne National Laboratory, Chicago, Ill.	University of Chicago.
Hanford Plutonium Works, Richland, Wash.	General Electric Company.
Knolls Atomic Power Laboratory, Schenectady, N.Y.	General Electric Company.
Ames Laboratory, Ames, Iowa.	Iowa State College.
Radiation Laboratory, Berkeley, Calif.	University of California.
Columbia Laboratories, New York, N.Y.	Columbia University.
Western Reserve Laboratories, Cleveland, Ohio.	Western Reserve Universities.

TOWN MANAGEMENT:

In addition to the above establishments, the United States Atomic Energy Commission manages the following towns, as part of the atomic energy production and research enterprise:

Oak Ridge (Tenn.)	... ...	Population 36,000.
Richland (Wash.)	... ...	,, 30,000.
Los Alamos (N. Mex.)	...	,, 8,000.

For the Argonne National Laboratory (the famous "Metallurgical Laboratory" of the Smyth Report), an elaborate and far-seeing scheme is being put into effect. An entirely new site of 3,700 acres in Du Page County, not far

from Chicago has been selected, where 13 nuclear science laboratories will be concentrated. This will be a research establishment without parallel anywhere in the world. Control descends directly from the Federal Government, through the U.S. Energy Commission, a Council, a Board of Governors, a Contractor (The University of Chicago) and a Director (Dr. W. H. Zinn).

No less than twenty-nine universities and colleges are participating institutions, with more than a third of a million students:—

Battelle Memorial Institute.
Carnegie Institute of Technology.
Case Institute of Technology.
University of Chicago.
University of Cincinnati.
University of Illinois.
Illinois Institute of Technology.
Indiana University.
Iowa State College.
State University of Iowa.
Kansas State College.
Loyola University.
Mayo Foundation.
University of Michigan.
Michigan State College.
Michigan College of Mining and Technology.
University of Minnesota.
University of Missouri.
University of Nebraska.
North-Western University.
Notre Dame University.
Ohio State University.
Oklahoma Agricultural and Mechanical College.
University of Pittsburgh.
Purdue University.
St. Louis University.
Washington University.
Western Reserve University.
University of Wisconsin.

Dr. Farrington Daniels, a member of the Board and former Chairman of the Governors of the Argonne Laboratory, states:—

"It is extremely important to bring American industry into the atomic energy program, particularly with reference to the design and construction of power piles."

It will be interesting to see how closely this ideal can be realized, and particularly as the Argonne Laboratory and the General Electric Company are both, independently, working out practical designs for a reactor for power production. It is understood that these designs will be of different types, and as both organizations have had several years of experience in reactor operation they have a unique advantage over similar teams anywhere else in the world.

B. In Canada

Canada has the distinction of being the second nation in the world, after the U.S.A., to build and operate an atomic energy reactor, the "ZEEP," at Chalk River. ZEEP stands for "Zero Energy Experimental Pile" and it uses heavy water as the neutron moderating material. As the temperature of the moderator must be kept well below boiling point, the power level is so low as to be purely nominal. In this respect it is not so useful as a "GLEEP"—"Graphite Low Energy Experimental Pile"—but the Canadians claim that their pile is unique in many respects and "provides the means of doing special types of research which no other pile in existence has." Apart from its heavy water moderator, little is known about "Zeep," except that it burns purified natural uranium in rod form, and has a highly efficient neutron reflector of graphite.

Chalk River is at a junction on the C.P.R., about 130 miles west of Ottawa. The actual atomic energy establishment is at a new town called "Deep River," which is about seven miles from Chalk River, and which exclusively provides homes and all the amenities of civilization for the personnel of the plant.

The entire Canadian atomic energy programme, including the control of the valuable reserves of uranium ore, is the responsibility of the Atomic Energy Control Board with headquarters at Ottawa. The President of the Board is General A. G. L. McNaughton. Under the National Research Council is a Division of Atomic Energy which is directly in charge of the Chalk River undertaking, and the stated objectives are:—

1. Obtaining data for engineers for atomic power development.
2. Nuclear physics research.
3. Preparation of Tracers for experiments in
   (a) Biology.
   (b) Chemistry.
   (c) Metallurgy and the preparation of radioactive sources for therapeutic work.
4. Radiation Chemistry.
5. Research on the chemistry of radioactive elements and isotopes.

To some extent the Canadian programme is limited at present by the low power of Zeep, as an irradiation reactor. A liquid moderator in a tank has its own peculiar features, as compared with a solid moderator, particularly in the reloading of the rods, the controls and access to the neutron flux for irradiation specimens. With a heavy water reactor, all this gear is preferably mounted on top of the reactor, which, of course, is completely enclosed in a heavy shield of concrete or metal. However, the Canadians will no doubt have had sufficient experience with Zeep to be already engaged in the design and construction of a high-powered unit.

C. In Great Britain

The pioneer nuclear research and discoveries of British scientists, and particularly of Lord Rutherford, Sir James Chadwick and Sir John Cockcroft, give Great Britain a unique background in atomic physics and she retains an important position in the fundamental work on which the successful development of atomic energy largely depends. For this reason, Britain, finding herself five years behind the U.S.A. in the technological and practical details, may nevertheless work out for herself some fundamental short cuts.

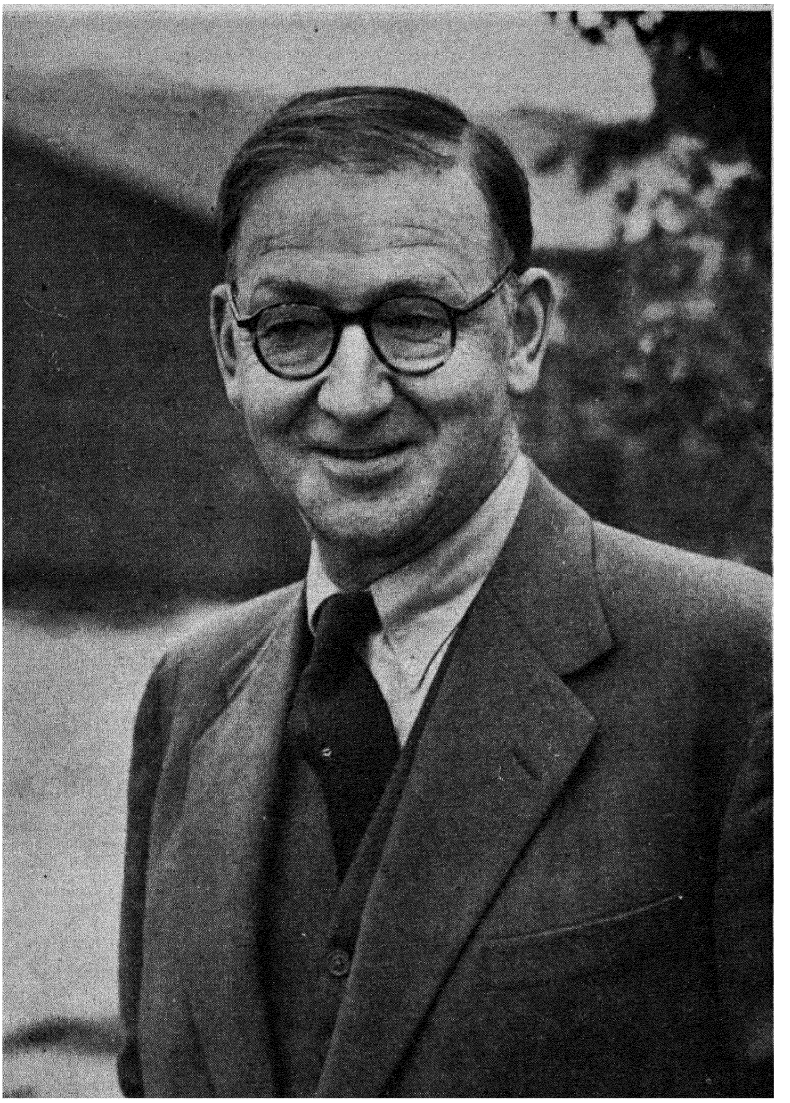
State control of atomic energy in Great Britain developed during the war years, side by side with similar controls in the U.S.A. and Canada, the three nations pooling their scientific knowledge in the common interest. In Great Britain a department was established under the code name "Directorate of Tube Alloys," the first director of which was W. A. Akers, now Sir Wallace Akers, F.R.S., the Research

Controller of Imperial Chemical Industries, Ltd. After the war, "Tube Alloys" emerged as the Department of Atomic Energy, under the Ministry of Supply, with headquarters at Shell Mex House, Strand, London, with Lord Portal of Hungerford, the famous R.A.F. leader, as Controller. Gradually the new department took shape. The great British radar establishment at Malvern was able to tackle immediately the advanced electronic problems inherent in the production of the wide variety of new-type instruments demanded by nuclear physics, and the availability of which is, of course, a pre-requisite for any work on atomic energy.

In the meantime, work proceeded with the laying out of the Atomic Energy Research Establishment (A.E.R.E.) at Harwell under Sir John Cockcroft, who had been on loan from Britain to Canada, as Director of Research at Chalk River. Harwell is planned on an ambitious scale and will no doubt satisfy current British research requirements, particularly as fundamental research on atomic energy is also in progress in almost every University laboratory in Britain, including such famous organizations as the Cavendish at Cambridge and the Clarendon at Oxford. In London alone, important work on different aspects of nuclear science is on hand at Imperial College, King's College, University College and Birkbeck College. At the many great provincial Universities such as Birmingham, Manchester, Liverpool, Durham, Edinburgh and Glasgow a great deal of high-geared research is in progress. At Bristol, British scientists are leading the world in the technique of using special photographic emulsions to detect and observe fundamental particles and reactions.

Simultaneously, the Department of Atomic Energy are operating three production establishments at Risley, Springfields and Drig for the development of the complex chemical, metallurgical and engineering operations associated with a full-scale atomic energy power plant. A separate radioisotope laboratory is located at Amersham. These several establishments are absorbing a rapidly increasing number of scientists and technicians.

The first Harwell pile, "Gleep," of 100 kW capacity, was followed, in July, 1948, by the second, "Bepo," of about 6,000 kW capacity. Both are of the graphite-moderated, air-cooled type. The uranium rods are enclosed in aluminium cases which lie in channels in the graphite. Cooling air is



[*Photo by permission of Planet News Ltd.*

Professor Sir John Cockcroft who, in 1932, demonstrated that the energy released in a nuclear reaction was exactly equal to the loss of mass.

drawn through the channels by powerful electrically driven exhausters, and is discharged at a height of 200 ft. above the ground. The power level of the reactor is governed by neutron-absorbing control rods, with separate stand-by controls for emergency use.

The fundamental design work was carried out by Sir John Cockcroft and his team at the Atomic Energy Research Establishment at Harwell and the details were developed by Mr. C. Hinton's team at the Risley establishment of the Department of Atomic Energy. The construction of "Bepo" was the responsibility of the Ministry of Works assisted by their contractors, Messrs. W. E. Chivers and Sons, Ltd., Devizes, Wiltshire. The overall size of the "Bepo" reactor is approximately 30 ft. by 30 ft. by 30 ft. including the shielding.

The terms of reference of the Research Establishment are to carry out work on research and development in atomic energy. This is interpreted as work primarily aimed towards the development of atomic power and, as a very important secondary objective, towards the provision of radioactive tracers for biological and other research. The task of highest priority was, therefore, the provision of atomic piles for experimental work and for the manufacture of tracers.

During the loading of the uranium, the multiplication constant, k, of the pile increased towards unity, and since one neutron released in the spontaneous fission of a U.238 nucleus leads to $1 + k + k^2$ or $1/(1 - k)$ neutrons, the course of approach to the critical or divergent state is followed by recording by a boron trifluoride-filled counter the flux of neutrons inside the pile.

The first pile is of very low power for experimental work and control of pile materials, and the second pile of higher power for experimental work and the manufacture of tracers. Basic work on these piles had begun before the initiation of the Harwell Establishment, at Chalk River, Canada, and in various firms in England. In August, 1947, the first pile started to operate. The concrete shield and its accessories had taken about one year to build. About the beginning of July stacking of the graphite began, and it was completed well ahead of schedule, in about one month. The uranium was then introduced slowly.

On August 7, when the pile contained several tons of uranium, the counter recorded 17 neutrons per minute. By August 11 the figure was 55 neutrons per minute, by the

[*Photo by Walter Stoneman.*

Professor Sir James Chadwick who, in 1932, discovered the neutron and identified its properties. Without neutrons there would be no possibility of harnessing atomic energy.

morning of August 15, 2,400 and by the afternoon 6,600. At this point the chamber saturated, the pile being almost divergent. During the last stages of loading, the control rods were partially inserted, reducing k slightly. Uranium was then loaded until the divergent point was just passed. At this stage the pile generated about 0.1 watt of thermal energy.

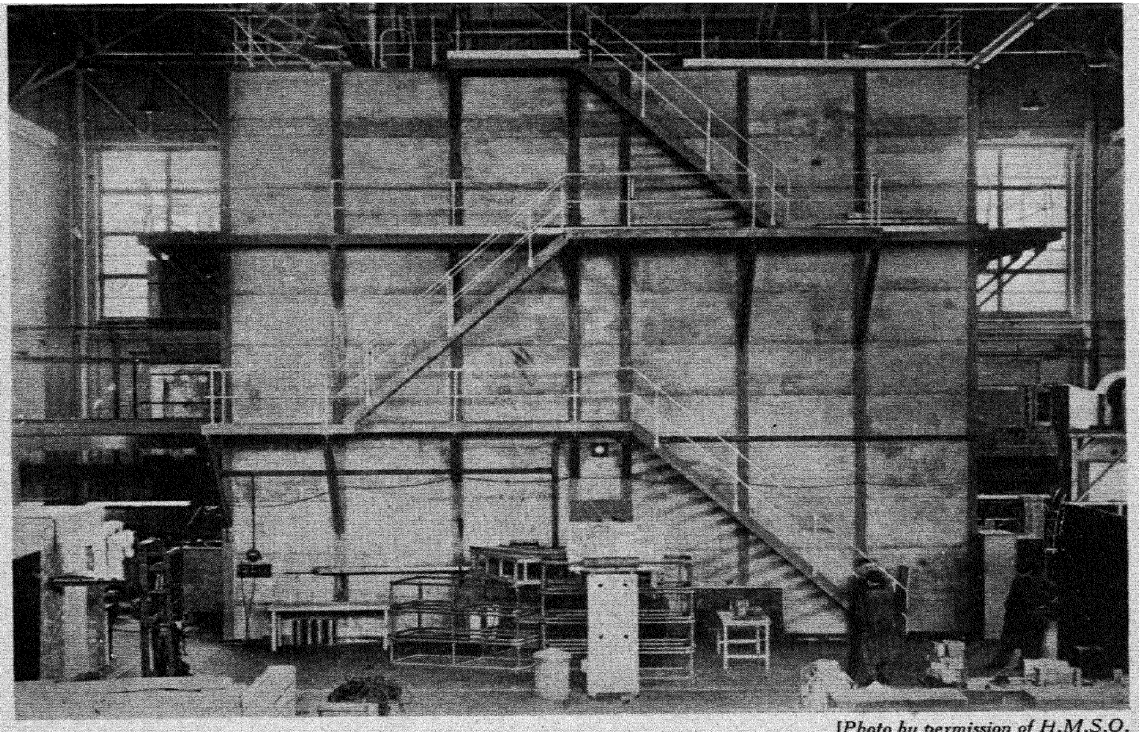
The power-level increases exponentially with time but with a very long period. The period depends on $1/(k-1)$, and with an excess of k of 1/40,000 the period is one hour. The pile is therefore very easy to control. A withdrawal of the control rods led to a decrease of the period to about a minute and the power-level was allowed to increase to 100 watts, at which level ionization chambers had been pre-set to release the shut-off rods and shut down the pile. The first objective of the Harwell work had, therefore, been realized in about 15 months.

Measurements have been carried out to determine all the pile characteristics. The power-level has been increased to a level set by the safe operating temperature of the uranium. In this pile only very simple cooling is used, and it would probably be necessary to limit the average power to about 50 kW. At this power-level there would be a maximum thermal neutron flux of 10^{10} neutrons per sq. cm. per sec.; the total number of neutrons generated would be about 3×10^{15} per sec., of which about 1 per cent. could be used for production of radioactive isotopes or for experimental work.

The second pile will operate at a neutron flux of something like 100 times that of the Gleep. This will make possible full production of nearly all the radio-active tracers required for Great Britain. A few useful isotopes will be limited in quantity and a few others manufactured only by the use of a cyclotron. The pile will also provide a powerful source of fission products, distributed among the 35 elements from zinc to gadolinium. At 1,000 kW, about 1 gm. per day will be produced. A small quantity of plutonium for experimental work will also be produced.

The pile will also be important in the study of the irradiation of various materials in an intense atmosphere of neutrons. Many of the properties of materials under such circumstances —materials of pile construction, for instance—are not yet known in Europe.

These piles will probably be followed by others, more



[*Photo by permission of H.M.S.O.*

General view of one face of Gleep. A neutron spectrometer, in which neutrons from the Pile are diffracted by a crystal, can be seen in the foreground.

directly concerned with power production. There are many problems yet to be solved. For instance, there must be a much more efficient use of uranium-235, the only naturally occurring fissile material, than is contemplated in existing types of pile. A more fundamental problem is to find out whether one can in some way use uranium-238 and thorium as nuclear fuels. Of course, it is known, for example, that uranium-238 is converted by neutron capture into plutonium, which is certainly a fissile material. But the only known way of doing this is to " burn " uranium-235. However, by the partial replacement of uranium-235 in a pile by plutonium it should be possible indirectly to " burn " some part of the uranium-238. In view of the obvious stringency of supplies of uranium-235 (present in natural uranium as only 1 part in 140), it will be important to find out how effectively such a process can be carried out in practice.

The Malvern group has been responsible for the provision of scalers for use with the counters and amplifiers for use with the ion chambers. Many more specialized problems also arise. A number of types of health instruments have been developed. For example, one of these is a hand monitor for making sure that the workers who have handled radioactive products have no residual activity left on their hands. Besides this, a number of instruments are being developed which are of great assistance in radiochemical work where a large amount of routine counting is required.

Then, also, there is the radiochemical work associated with the extraction and properties of highly active materials.

During the war the development of mass spectrographs was undertaken in England. These have now become available and have led to research into the field of non-radioactive tracers, which are simply enriched specimens of known stable isotopes such as C.13. For many biochemical uses these are preferable to the radioactive tracers since they do not involve active doses, and also elaborately prepared organic compounds do not decay away. Further, one element which is important, nitrogen, has no suitable active isotope.

Work is in hand at Harwell towards the preparation of inactive tracers, the most important of which are D, C.13, N.15, O.18, and S.32. It was known that N.15 was being produced in the U.S.A. by a method known as chemical exchange. This is a reaction between ammonia and a solution of ammonium nitrate which tends to concentrate the heavier

isotope N.15 in the solution. The work is done by allowing the gas to interact with the solution, which wets a large area of so-called " packing " in a long vertical column. The process is used commercially in the U.S.A. and a similar plant may also be set up in England in the near future. With C.13 and O.18 similar processes can probably be used, but there are difficulties. At Harwell they are working on a modified process in which gaseous CO^2 is allowed to interact with liquid CO^2 at roughly liquid air temperature. This process shows considerable promise.

These methods are specialized for particular isotopes, but the target is to have available methods by which the isotope of any element can be prepared in small quantities. The simplest general method is that of thermal diffusion, in which a gas is placed in a long, vertical column down which passes a heated wire or rod. The molecules containing the heavier isotope tend to concentrate at the cool outer wall, while those of the lighter isotope concentrate near the hot surface. Thus a convection is set up in which the lighter isotope is concentrated at the top of the tube. Several such tubes placed in series will give the required concentration of 20 to 50 times.

Machines which are constructed or under construction for particle acceleration are:

(1) Van de Graaff machine for protons or deuterons of 4 or 5 Mev.
(2) Synchro-cyclotron for protons of 150 Mev energy.
(3) Synchrotron for fast electrons.
(4) Linear accelerator for fast electrons.

For the production of radioactive isotopes at Harwell the procedure is to produce them by neutron capture. The materials to be irradiated are placed in the reflector of the pile, where up to one fortieth of the pile neutrons can be absorbed for this purpose. Some biological experiments require a high specific activity—500 millicuries per gram of materials. For this purpose it might be necessary to use (n, p) reactions, for example, in S.32 (n, p) P.32. Many of these reactions require fast neutrons and can be produced only in the core of the pile, where the available neutrons will be only about one-tenth of those available in the reflector. A few isotopes such as tritium would be produced by (n, α) reactions. The high-power Harwell pile would be able to produce quantities of most isotopes more than adequate for all requirements. A few long-lived isotopes such as tritium,

C.14, C.137, would be limited by pile capacity, though an annual production of 4.5 curies of C.14 should be possible.

It is expected that a few radioactive isotopes, such as Na22, will still have to be produced in the cyclotron, since they can be produced only by (n, 2n) reactions which require very fast neutrons.

Radioactive isotopes produced by (n, p) reactions would require chemical separation; and when the processes have been established at the Harwell station, routine separation will be carried out by the Radiochemical Centre of the Ministry of Supply. The allocation of radioactive isotopes will be carried out by a sub-committee of the Advisory Council for the Radiochemical Centre. This sub-committee, under the chairmanship of Dr. J. D. Cockcroft, includes representatives of user interests—the Medical and Agricultural Research Councils and the Department of Scientific and Industrial Research, which will represent the universities and industry.

In order to comply with Treasury requirements on expenditure of dollars and with the arrangements made with the American authorities, requests for U.S. isotopes must be sponsored by an appropriate authority: for medical and biological research, and for therapeutic uses, the Medical Research Council (inquiries to the Secretary, Medical Research Council, 38, Old Queen Street, S.W.1); for agricultural and veterinary research purposes, the Agricultural Research Council (inquiries to W. G. Alexander, 6a, Dean's Yard, Westminster, S.W.1); for research in other branches of science, and for industrial research, the Department of Scientific and Industrial Research (inquiries to the Secretary of the Department, 24, Rutland Gate, S.W.7). A number of consignments of isotopes have been received under this arrangement, mostly for medical research purposes.

D. In Europe, Asia, Africa, India, Australia and South America

France

With Henri Becquerel and the Curies as the pioneer discoverers of radio-activity and of radium, respectively, France, like Britain, has an historic place in the development

of nuclear science. Appropriately, a former colleague of Marie Curie, Professor Pierre Joliot, is High Commissioner of the French Atomic Energy Commission and Director of the Centre National de la Recherche Scientifique. The Scientific Director of the French A.E.C. is Dr. L. Kowarski, a distinguished collaborator of Joliot in fundamental research on fission. The other members of the Commission are Professors Irene Joliot-Curie, Pierre Auger, Francis Perrin and official representatives of state departments.

The French programme is at present on a relatively small scale compared with that of the U.S.A. or even Britain. Measured in items of current expenditure the ratio between the programmes of the U.S.A. and France is of the order of 100 to 1.

The French Atomic Energy Research Establishment is at Fort de Chatillon, near Paris, with administration head offices in the city and a chemical and metallurgical plant at Le Bouchet (30 miles out of Paris). A permanent research centre is being built at Saclay (10 miles out of Paris).

France made plans originally for a fairly advanced design of reactor, but soon ran into difficulties, mainly in connection with the extremely high standards of purity required in uranium metal, graphite, and even in heavy water. As a result, the first reactor will be an uncooled heavy water reactor, using uranium oxide, the maximum power level being only a few kilowatts. It is hoped that this will be completed and in operation before the end of 1948 or early in 1949.

BELGIUM

The development of atomic energy, even in a modest way, calls for quite a major effort and a considerable outlay in capital, technical staff and labour. It is possible that the Belgian Government have decided that a large-scale programme is not at present opportune. In the meantime, easily the richest deposits in the world of uranium ore are in the Belgian Congo, which has always been, and still remains, the largest supplier of these ores to the U.S.A. These mineral deposits make the Belgian contribution to atomic energy of first-class and unique importance.

HOLLAND

Dr. K. A. Kramers, the distinguished Professor of

Theoretical Physics at Leyden University, is one of the leaders of atomic energy research, largely based on the Physical Research Laboratories of the famous Philips Company, at Eindhoven, under their research director, Dr. Casimir, supported by research laboratories at Amsterdam, Leyden and Delft Universities. An Institute for Nuclear Physics Research has been established under the Directorship of Dr. C. J. Bakker. The Philips group have established an international reputation as designers and manufacturers of particle accelerators for atomic research, and this, for the present, is Holland's main line of development.

DENMARK

From the famous Institute of Theoretical Physics at Copenhagen have come many contributions of profound importance to nuclear science, and in particular the already classical work of Neils Bohr. Hevesy, who is also at Copenhagen, is another Nobel prizewinner in the field of nuclear chemistry. Certainly Denmark can claim to be second to none in the development of fundamental research, but lacks the industrial potential to take full advantage of this in practical applications.

NORWAY

For many years, indeed before nuclear fission was discovered, Norway was the world's largest producer of heavy water, at the Norsk Hydro Plant, since famous for the Anglo-Norwegian Commando raids, to prevent the Germans from obtaining the supplies of heavy water which would have accelerated their production of an atom bomb. It is certain that Norwegian scientists are planning a heavy water reactor, but whether it has gone beyond the blue-print stage is doubtful. The French bought two years' supply of heavy water from Norway—which would represent a considerable capital outlay—but found that the engineering and metallurgical problems involved in a closed circuit heavy water reactor with an external heat exchanger are quite formidable, and not essential for low power. Possibly the Norwegians in the first instance will build a reactor similar to the simplified French design at Chatillon.

SWEDEN

It is understood that Sweden is building or has already

built a reactor, and is favourably placed for this in having a high industrial potential for a relatively small nation, particularly in electrical and mechanical engineering. It remains to be seen whether the Swedes prefer the heavy water or the graphite type.

SWITZERLAND

It might not have been unreasonable to assume that a large-scale atomic energy establishment would be beyond the capacity of a small country such as Switzerland. But this clever and enterprising nation is right in the front line on the engineering technique which the industrial application of nuclear power demands. For example, the Escher-Wyss Company are probably leading the world in closed cycle gas turbine design, particularly using helium, which has special advantages for atomic energy. Switzerland has an Atomic Energy Commission, the President of which is Dr. Paul Scherrer, a distinguished physicist of international reputation.

GERMANY

Despite the fact that the original discovery of nuclear fission was made in Germany in 1938 by two German scientists, Hahn and Strassman, Allied fears that Germany might establish a lead in atomic weapons proved unfounded, possibly due to the depletion of the number and quality of top-ranking physicists. At present, any investigations in Germany on nuclear physics are severely controlled, but it is certain that the nation which gave the world such men as Planck and Einstein, will in course of time make further notable contributions to the march of science.

U.S.S.R. AND EASTERN EUROPE

Very little information is available on these countries. In scientific and industrial capacity and resources of raw materials, their combined strength is very substantial. The Chair of Nuclear Physics at Moscow University is held by Dh. D. V. Skobeltskin, who also represented the U.S.S.R. on the United Nations Atomic Energy Commission.

ITALY

Nuclear research and discoveries of the greatest importance have been contributed by Italy, led by that remarkable

scientist, Fermi, who combines the most advanced conceptions in theoretical nucleonics with the practical ability to translate them into realities, as for example, in the Chicago pile. Other Italian scientists such as Amaldi are engaged on important work, particularly in continuing the pioneer work on neutron properties, initiated by Fermi in Rome.

India and Pakistan

The Government have appointed an Atomic Energy Commission. Indian scientists are famous for their genius for advanced mathematical research, which is of special value in nucleonics and the quantum mechanics associated with it. India has extensive goldfields, which are frequently a pointer to the occurrence of uranium ores, whilst Ceylon is potentially the world's richest source of thorium.

Africa

As already stated, the richest deposits of uranium ore are in the Belgian Congo. The great South African goldfields are also known to cover resources of uranium ore to an extent which probably defies even a rough estimate. The Government have embarked on a considerable programme of prospecting, and have also imposed a close control.

Australia

An intensive search for raw materials is in progress. It is established that Australia has deposits of uranium ores but what proportion is recoverable as a commercial proposition is an unknown quantity. In the meantime, Australia has a special interest in the development of atomic energy as a source of power, as she has vast areas remote from fuel supplies or water power, where the possibility of large-scale irrigation, using atomic energy has been seriously considered.

South America

The Latin countries of the Southern Hemisphere have not *revealed* any great interest in atomic energy, but that by no means indicates that nothing is being done. On the contrary, it is probable that any nation to-day finding sources of uranium or thorium ores in significant quantities would be wise to give the discovery a news value in inverse proportion to its atomic energy importance.

CHAPTER VIII

LEGAL ASPECTS

IN almost every country, atomic energy, its production and raw materials, have been placed under the control of the State. In effect this means that except with State permission, no private person or organization may own or deal in any property relevant to atomic energy, from raw materials to patents. There also exists in most countries State control over therapeutic radioactive materials and their radiations.

As an example of the legislation involved, summaries are given of the British Atomic Energy and Radio-active Substances Bills. It may be accepted that the general effect is similar in most other countries where State control is established.

Atomic Energy Act, 1946 (Great Britain)
Summary of Essential Features

RESPONSIBLE MINISTER.

Minister of Supply, Department of Atomic Energy, Shell Mex House, Strand, London, W.C.2.

POWERS.

General duty is to "promote and control" the development of atomic energy, and general powers in connection therewith, including prospecting for and mining of minerals. Minister may make grants or loans to any person engaged in the production or use of atomic energy, or research thereon. Power to obtain detailed information of materials, plant and processes, and contracts.

Power of compulsory acquisition, *subject to compensation*, of stocks of minerals, plant, contractual right, and inventions.

CONTROL OF PRODUCTION AND USE OF ATOMIC ENERGY.

1. The Minister may by order provide for prohibiting, except under the authority of a licence granted by the Minister:—

(a) the working of any minerals specified in the Order, being

minerals from which in the opinion of the Minister any of the prescribed substances can be obtained;

(b) the acquisition, production, treatment, possession, use, disposal, export or import,

(i) of any of the prescribed substances;

(ii) of any minerals specified in the order, being minerals from which in the opinion of the Minister any of the prescribed substances can be obtained and not being minerals in a natural state or contained in a deposit of waste material obtained from any underground or surface working, or

(iii) of any plant designed or adapted for the production or use of atomic energy or for research into matters connected therewith.

2. The Minister shall secure so far as practicable, by the issue of licences in such cases or classes of cases as he thinks fit, that such minerals, subtances and plant as aforesaid are available for purposes of research and education, for medical and biological purposes and for commercial purposes not involving the production or use of atomic energy.

RESTRICTION ON DISCLOSURE OF INFORMATION RELATING TO PLANT.

Any person who without the consent of the Minister communicates to any other person except an authorized person[1] any document, drawing, photograph, plan, model or other information whatsoever which to his knowledge describes, represents or illustrates—

(a) any existing or proposed plant used or proposed to be used for the purpose of producing or using atomic energy;

(b) the purpose or method of operation of any such existing or proposed plant; or

(c) any process operated or proposed to be operated in any such existing or proposed plant;

shall be guilty of an offence under this Act.

[1] Under a strict interpretation of this clause, the permission of the Minister would be necessary before employing stenographers, typists, draughtsmen, solicitors and patent agents on atomic energy work.—[EDITOR.]

SPECIAL PROVISION AS TO INVENTIONS.

Where it appears to the Comptroller-General that the invention relates to the production or use of atomic energy or research into matters connected therewith, he shall serve a notice in writing on the Minister to that effect, and give directions for prohibiting or restricting the publication of information with respect to the subject matter of the application, or the communication of such information. The Minister shall forthwith consider whether the invention is of importance for the purposes of defence.

No person resident in the United Kingdom shall, except under the authority of a written permit granted by, or on behalf of, the Comptroller-General, make any application outside the United Kingdom for the grant of a patent for an invention which relates to the production or use of atomic energy or research into matters connected therewith.

The power of the Minister of Supply shall include power to make, use, exercise or vend an invention, for such purposes relating to the production or use of atomic energy or research into matters connected therewith as the Minister thinks necessary or expedient, and the terms of any licence or agreement concluded between the inventor or patentee of an invention and any person other than the Minister shall be inoperative so far as concerns the making, use, exercise or vending of that invention by the Minister.

PENALTIES.

Any person guilty of an offence under this Act shall be liable—

(a) on summary conviction, to imprisonment for a term not exceeding three months or to a fine not exceeding one hundred pounds, or to both such imprisonment and such fine; or

(b) on conviction on indictment, to penal servitude for a term not exceeding five years or to a fine not exceeding five hundred pounds, or to both such penal servitude and such fine.

Where a person convicted on indictment of an offence under this Act is a body corporate, the provision of the foregoing subsection limiting the amount of the fine which may be imposed shall not apply and the body corporate shall be liable to a fine of such amount as the court thinks just.

Where any offence under this Act has been committed by a body corporate, every person who at the time of the commission of the offence was a director, general manager, secretary or other similar officer of the body corporate shall be deemed to be guilty of that offence, unless he proves that the offence was committed without his consent or connivance and that he exercised all such diligence to prevent the commission of the offence as he ought to have exercised having regard to the nature of his functions in that capacity and to all the circumstances.

DEFINITIONS UNDER THE ACT.

In this Act the following expressions have the meanings hereby respectively assigned to them, that is to say—

" Atomic energy " means the energy released from atomic nuclei as a result of any process, including the fission process, but does not include energy released in any process of natural transmutation or radio-active decay which is not accelerated or influenced by external means;

" Prescribed substance " means uranium, thorium, plutonium, neptunium or any of their respective compounds or any such other substance as the Minister may by order prescribe, being a substance which in his opinion is or may be used for the production or use of atomic energy or research into matter connected therewith.

Radio-Active Substances Bill, 1948 (Great Britain). Summary of Essential Features

RESPONSIBLE MINISTER.

Minister of Supply, Department of Atomic Energy, Shell Mex Hou e, Strand, London, W.C.2.

POWERS.

General control over the production, transportation, sale, supply and export of radio-active substances. Specification of safety regulations. Powers of entry and inspection. Issue of licences to users.

CHAPTER IX

DESIGN OF RADIATION LABORATORIES AND ORGANIZATION OF SAFETY TECHNIQUE

THE design of a radiochemical laboratory is *largely determined* by the nature of the precautions which must be taken in order that the work may be carried out without damage to the operators. These precautions are dependent upon the type of radiation which is concerned, i.e., whether α-rays, β-rays, or γ-rays, and on its intensity.

α-Rays (high velocity doubly charged helium atoms), are very strongly ionizing but have only a short path through matter. They do not penetrate ordinary laboratory glassware or rubber gloves. α-emitting materials can therefore be handled if rubber gloves are worn.

β-Rays (high velocity electrons) have a path of many centimetres in air and will penetrate the walls of glass vessels. Vessels should be handled by means of tongs.

γ-Rays (short wave-length electromagnetic radiation), will penetrate several centimetres of lead and several metres of air. Vessels and apparatus must be placed behind lead or concrete walls.

Bearing in mind the characteristic properties of the radiations, radio-active material can be divided into the following classes from the point of view of laboratory layout:

1. High β and γ activities (> 1 curie); operations carried out by remote control in totally enclosed concrete cell.

2. Moderate β and γ activities (< 1 curie); operations carried out behind lead walls, in fume cupboards.

3. α-Active materials: no special precautions against radiation are necessary, other than the wearing of gloves, but owing to the very low tolerance levels of the body for α-emitters, exceptional care must be taken to avoid their absorption into the system. All operations must be carried out in closed cabinets or in fume cupboards.

4. Tracer activities (< 10 microcuries); in general, the normal precautions of an ordinary chemical laboratory are adequate, provided the hands are protected by rubber gloves.

A separate section of the radiochemical laboratory must be allocated to each of these classes in such a way as to keep the

highly active work as far away as possible from the work at very low activities. One convenient arrangement is to have a central block containing administration, stores, and inactive or tracer laboratories, etc., a wing for β, γ-active work and a wing for α-active work. High γ-activities should be confined to the remote end of the β, γ-wing, which should have concrete walls, at least 1 ft. in thickness or the equivalent of brick. Floors and benches must be strong enough to bear loads of several hundred pounds of protective lead. The α-wing can be of normal construction but the laboratories should be designed so as to avoid the accumulation of dust.

Safe Handling of Radioactive Isotopes

The strict observance of safety rules is a pre-requisite in any atomic energy or radiation laboratory. The following are the standard safety requirements of the U.S. Atomic Energy Commission. It may be assumed that the rules in force at British and Canadian establishments are substantially similar.

Although the regulations may appear somewhat stringent, it will be understood that they are vital to the successful development of atomic energy and to the practical applications to medical and industrial research of its radio-active by-products. Non-government laboratories should, of course, consult the authorities for assistance in setting up safety controls best adapted to their requirements.

I. GENERAL CONSIDERATIONS

(a) PREFACE TO RECOMMENDATIONS

Prior to the war, the use of radioisotopes was essentially limited to a few locations having access to cyclotron-induced activities. The addition of pile-induced activities, either as fission products or as special irradiations, has changed the magnitude of the related protection problems. Widespread laboratory and industrial use of radioisotopes is foreseen. This involves the protection of scientists and technicians in one case, of industrial employees in the other, and of the public in both cases. This chapter cannot give detailed recommendations, necessary and sufficient for all cases. It is, therefore, planned to give the general recommendations suitable for

typical laboratory or small industrial operations. In all cases, management specifically assumes the responsibility for the proper selection and maintenance of the standards necessary for safe operation. The small laboratory, handling low levels of radioactivity may modify or omit some of the following recommendations. A periodic review of such modifications by a competent radiation protection authority may be desirable. The large laboratories and industries will require more detailed control. The employment of full-time personnel qualified in radiation protection is then desirable, and should be mandatory where the staff handling radioactive material exceeds 25.

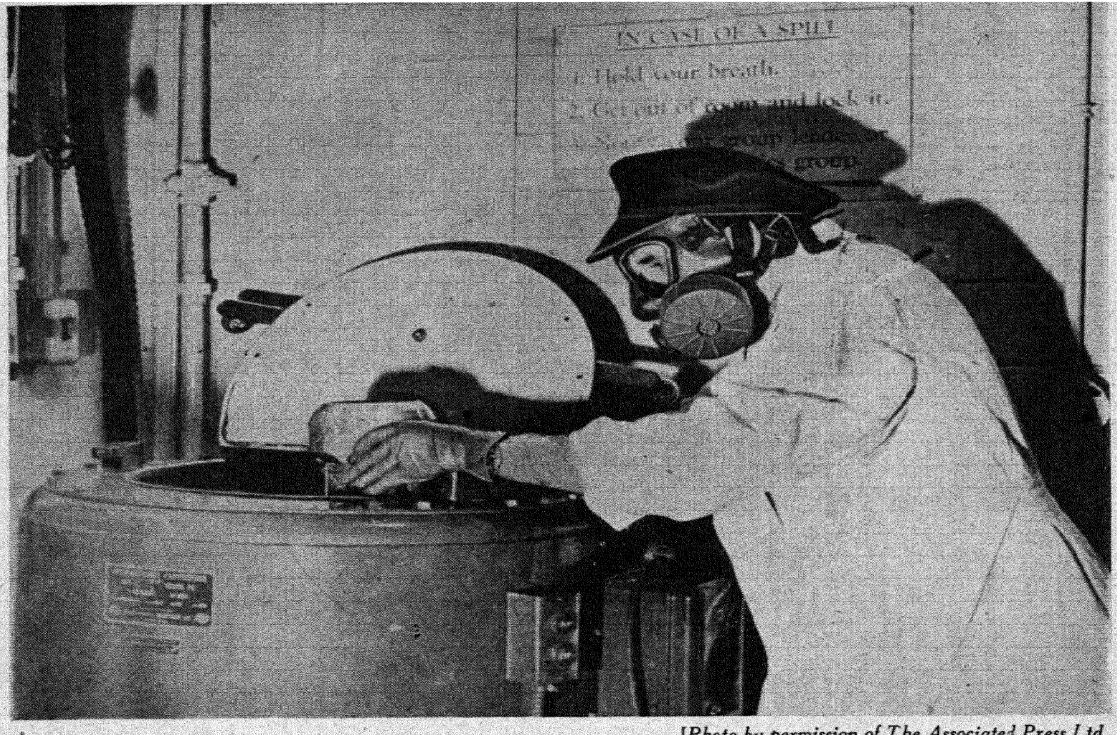
Specific attention is directed to the usage of "shall" and "should" throughout the recommendations. The former is used in a mandatory sense. The latter applies to those recommendations that may be redundant at low activity levels, optional at intermediate levels, and essential at high levels.

(b) Available Isotopes

Table 1 lists the radioisotopes of generally greatest interest, and indicates the order of magnitude of the amounts normally available. A knowledge of the sites of deposition and elimination routes is a partial requirement for the hazard evaluation and tests for each particular isotope. Severe radiation hazard is associated with those isotopes that have unfavourable combinations of long half-life, high uptake, deposition in small organs or in bone, and low elimination rates.

Table 2 shows the common isotopes sub-divided into three groups, according to relative radiotoxicity following accidental intake into the body. The diagram attempts to define the ranges of low level, intermediate level, and high level activity used in the laboratory, with respect to intake hazards.

When the hazard is confined to that from external radiation, low, intermediate and high levels are normally considered in terms of the emitted gamma radiation. These levels are not defined in this draft, because the required safeguards are more widely understood in this case. It will be clear from the context whether a level is considered from the toxicity or external irradiation standpoint. Those isotopes which are preeminently gamma emitters are indicated by asterisk in the table. The handling of those few isotopes that are alpha emitters is not specifically included in this draft.



[*Photo by permission of The Associated Press Ltd.*

Radio-isotopes : protection of operators.

(c) HAZARDS IN HANDLING RADIOISOTOPES

The known hazards may be classified in the order of their importance as follows:

(1) Deposition of radioisotopes in the body.
(2) Exposure of the whole body to gamma radiation.
(3) Exposure of the body to beta radiation.
(4) Exposure of the hands or other limited parts to beta or gamma radiation.

The hazards may be briefly described as follows:

(1) Deposition may result from ingestion, inhalation or absorption through the intact or injured body surface. Ingestion may occur as an acute problem through the accidental drinking of an active solution. More generally, it will be a chronic problem caused by accumulation of small amounts of activity on contaminated hands, cigarettes and other items brought to the mouth, or as a secondary result of inhalation. Following ingestion, the hazard may be due to direct irradiation of the alimentary tract, or more probably due to chronic irradiation of the organs in which the particular active materials are concentrated (e.g., strontium isotopes will accumulate in the bone, and iodine isotopes in the thyroid gland). Inhalation of active gas, vapour, spray, or dust, may occur. Exposure to spray or dust is considered particularly hazardous because of the large fraction of such contamination retained by the lungs. Following inhalation, the hazard is threefold:

(a) Direct irradiation of the lungs, etc.

(b) Absorption of the active material directly from the lung.

(c) Elimination from the lung by ciliary action followed by ingestion.

Chronic deposition of unabsorbable particles in the lungs is a major hazard since it is extremely difficult to demonstrate the accumulation of such particles. Once radioactive material has entered the body and been deposited in the organs governed by its metabolism, it is difficult or impossible to expedite the natural rate of elimination from the organ. It is, therefore, essential to avoid all ingestion in inhalation of radioactive materials and to test potentially exposed personnel for such accumulations whenever a suitable method exists.

Absorption of active materials through an open cut or

Table I.—Properties of the

	Isotope	Half life	Energy (Mev)		Est. quantities available	Principal uses
			Beta	Gamma		
1	H^3	3ly	0.014	—	(mc) mc	Trace for H, auxiliary for C
2	C^{14}	5100y	0.154	—	mc	Labeled organic compounds
3	Na^{24}	14.8h	1.4	1.4, 2.8	200	Tracer studies of Na metabolism, diagnostic tests
4	P^{32}	14.3d	1.69	None	1500	Therapy, diagnosis P chemistry, PO_4 tracers
5	S^{35}	87.1d	0.17	None	1.0	Tracer on sulfur drugs, analytical chemistry
6	Cl^{36}	10^6y	0.66	None	0.005	Cl chemistry, tracer gas
7	K^{42}	12.4h	75%–3.58 25%–2.07	1.51 (25%)	130	Tracer study of K compounds
8	Ca^{45}	180d	0.25	None	1.0	Studies of Ca deposition, analytical chemistry, alloy studies
9	Mn^{52}	6.5d	K, e+	0.56, 0.73, 1.46	100	Trace biology
	Mn^{54}	310d	K	0.835	1.0	
10	Fe^{55}	4y	K	0.07	1.0	Trace on Fe drugs, blood chemistry
	Fe^{59}	44d	0.26, 0.46	1.1, 1.3	1.0	Fe chemistry
11	Co^{60}	5.3y	0.3	1.1, 1.3	200	Trace biology, gamma source, Co chemistry, alloy studies
12	Cu^{64}	12.8h	$0.58\beta^-$ $0.66\beta^+ + K$	1.2 (weak)	1.0	Trace biology, alloy studies, Cu chemistry
13	As^{76}	26.8h	1.1, 1.7, 2.7	0.57, 1.25	30	Tracer studies with arsenical drugs
	As^{77}	40h	0.8	None	1.0	Alloy studies
14	Sr^{89}	55d	1.5	None	1000	Sr chemistry
	Sr^{90}	25y	0.65	None	mc	
15	I^{130}	12.6	0.61, 1.03	0.42, 0.54 0.67, 0.74	250	Thyroid tracers, thyroid therapy
	I^{131}	8d	0.6	0.367, 0.080	130	I chemistry
16	Ba^{131}	12d	K, e–	1.2 (weak)	6.0	Metabolism of F.P.
	Ba^{140}	12.8d	1.05	0.542	mc	Analytical chemistry
17	Au^{198}	2.7d	0.97	0.44	80	Alloy studies
	Au^{199}	3.3d	1.01	0.45	10	Au chemistry
18	Ng^{197}	(64h	(K, e–	(0.075	100	Low energy gamma source
	Ng^{203}, ^{205}	(25h 51.5d	(K, e– 0.3	(0.13, 0.16 0.28	150	Alloy studies
19	Bi^{210}	5d	1.17	None	10	Tracer studies of Bi drugs

(1) Calcium absorption and excretion is dependent on blood calcium level.
(2) Iron absorption from the gut is influenced by the level of iron present in the blood and liver. Once iron enters into the metabolism of the animal, the excretion rate for that iron is very low.
(3) As—Retention in all tissue is very low.
(4) Sr—Absorption and deposition (5 to 80% in bone vary with age and existing Ca level.
(5) Doses in excess of 0.1 gm. give a low retention.

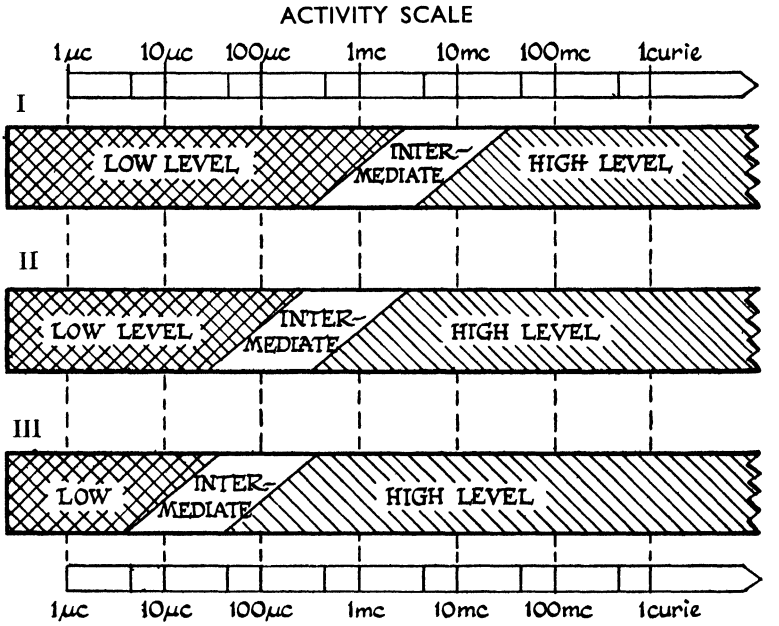
Principal Radioisotopes

		Metabolism								
		Ingestion			Inhalation			Parenteral		
		Abs.	Deposition	Elim.	Abs.	Deposition	Elim.	Abs.	Deposition	Elim.
1		X	X	X	Same	Same	Same	Same	Same	Same
2		X	Bone—L X	Lung Feces Urine	Same	Same	Same	Same	Same	Same
3		High	Body Fluids—H	Urine	Same	Same	Same	Same	Same	Same
4		High	Bone—M	Urine	High	Bone—M	Urine	High	Bone—M	Urine Feces
5		X	Liver All protein	Urine	Same	Same	Same	Same	Same	Same
6		High	Body Fluids—H	Urine	Same	Same	Same	Same	Same	Same
7		High	Blood—H Muscle	Urine	Same	Same	Same	Same	Same	Same
8	(1)	*	Bone—H	Feces Urine	Same	Same	Same	Same	Same	Same
9				Feces	Same	Same	Same	Same	Same	Same
10	(2)	*	Blood—H	Feces	Same	Same	Same	Same	Same	Same
11			Bone ?	Urine	Same	Same	Same	Same	Same	Same
12			Liver	Urine	Same	Same	Same	Same	Same	Same
13	(3)	Low	Bone—M Hair—L	Feces Urine	Same	Bone—M Hair—L	Urine	X	Bone—M Hair—L	Urine
14	(4)	*	Bone—H	Feces Urine	X	Bone—H	Feces Urine	X	Bone—H	Feces Urine
15	(5)	High	Thyroid 20%	Urine	Same	Same	Same	Same	Same	Same
16		*	Bone marrow	Feces	Same	Same	Same	Same	Same	Same
17		X	Liver—M	Feces Urine	X	Liver—M	Urine	X	Liver—M	Urine
18		X	Liver Kidney		Same	Same	Same	Same	Same	Same
19		Low	Kidney Liver		Low	Same	Same	Same	Same	Same

X—Indicates chiefly dependent on compound.
*—Indicates information in footnote.
H, L and M—Indicate high, low or moderate % deposit out of total amount absorbed.

Table 2

Selected Radioisotopes grouped according to Relative Radiotoxicity, with the amounts considered as Low, Intermediate or High Level in Laboratory Practice.



Group I. SLIGHT HAZARD

*Na^{24}, K^{42}, Cu^{64}, *Mn^{52}, *As^{76}, As^{77}, Kr^{85}, *Hg^{197}.

Group II. MODERATELY DANGEROUS

H^3, P^{32}, *Na^{22}, S^{35}, Cl^{36}, *Mn^{54}, *Fe^{59}, *Co^{60}, Sr^{89}, *Cb^{95}, Ru^{103}, Ru^{106}, Te^{127}, Te^{129}, I^{131}, *Cs^{137}, *Ba^{140}, *La^{140}, Ce^{141}, Pr^{143}, *Nd^{147}, *Au^{198}, *Au^{199}, Hg^{203}, ^{205}.

Group III. VERY DANGEROUS

C^{14}, Ca^{45}, Fe^{55}, Sr^{90}, Y^{91}, *Zr^{95}, Ce^{144}, 61^{147}, Bi^{210}.

Notes :

1. Effective radiotox ty is obtained from a weighting of the following factors.
   (a) Half-life.
   (b) Energy and character of radiations.
   (c) Degree of selective localization in the body.
   (d) Rates of elimination.
   (e) Quantities involved and modes of handling in typical experiments.

2. The slant boundaries between levels indicate borderline zones, and emphasize that there is no sharp transition between the levels and the associated protection techniques.

3. The principal gamma-emitters are indicated by asterisk. (e.g. *Na^{24}). The above level system does not apply to the hazards of external irradiation.

even through the intact skin, is a potential hazard when more than tracer doses are handled. Retention of activity in the skin itself is known to be able to produce tumours.

(2) The whole body exposure to gamma radiation shall not exceed 500 mr per week. According to present knowledge, this general exposure to gamma radiation is believed to be safe as far as any bodily injury is concerned, when there is no other type of radiation exposure. The importance of possible genetic change effective in later generations is open to question.

(3) When the body is exposed to an external source of beta radiation, only the superficial layers up to a few millimeters in thickness are irradiated. Nevertheless, for safety, the limiting general exposure to external beta radiation should be taken as 500 mrep[1]. per week in the surface layers. The outermost layer of skin is considered to be a dead hornified layer, which acts as a filter, and the dose is computed for the zone immediately below this. The filter thickness is taken as 7 mg. per cm^2, except on the palms, where it is about 40 mg. per cm^2.

(4) Earlier practice in the handling of radium and related compounds condoned the acceptance of greater exposure of limited parts of the body, specifically the hands or the head, in comparison with whole body exposure. The recommended practice, however, is to limit the exposure of these parts to that which is acceptable for the whole body. The calculated exposure is to include that due to radioactive contaminants deposited in the skin.

In connection with the four types of hazards enumerated above, it is important to bear in mind that the tolerance as

[1]The "rep" is a convenient shorthand notation for statements of dose of ionizing radiation not covered by the definition of the roentgen. It represents that dose which produces energy absorption of 83 ergs per gram of tissue. The actual energy absorption in tissue per roentgen is a function of the tissue composition and of the wavelength of the radiation. It ranges between 60 and 100 ergs per gram. For permissible exposure calculations this variation is ignored, and a beta-ray dose of one rep is said to be physically equivalent to an X-ray dose of one roentgen. Biological equivalence requires the additional consideration of at least (1) specific ionization, (2) protraction, (3) fractionation of successive small doses. The related shorthand "rem" is used to describe that dose of any ionizing radiation that will produce the same biological effect as that produced by one roentgen of high-voltage X-radiation.

Neither the "rep" nor the "rem" has any recognized status as a formal *unit*.

quoted applies under conditions where only one hazard exists. In the handling of radioisotopes, all four hazards exist together, and this may reduce the permissible exposure to each. Linear additivity of the ionization contributions at any point in the body from the four enumerated causes is assumed. In particular, the total irradiation of any part of the body should not exceed 500 mrep per week.[2] It is advisable to keep well below the quoted tolerances whenever mixed exposures may occur, because of the increased difficulty of registering such exposures accurately.

(d) PRINCIPLES UNDERLYING PROTECTIVE MEASURES

The fundamental purposes of protective measures in the handling of radioisotopes are:

(1) to prevent ingestion, inhalation, interstitial, or other types of absorption into the body.

(2) to reduce the amounts of external radiation to tolerable levels.

The first requirement is fulfilled by good housekeeping and work habits, and by operation in a laboratory properly equipped for the handling of isotopes, including protective covering, manipulative devices, suitable ventilation, and waste disposal facilities. The second requirement, maintenance of satisfactory levels of external radiation, is governed by procedures such as those contained in the National Bureau of Standards Handbook H-23 entitled "Radium Protection," which should be available to all persons working with radioisotopes. Special requirements arise when isotopes with beta activity, essentially free from gamma activity, are used.

Laboratories which specialize in the use of a few isotopes should become familiar in detail with the published data on the metabolism and estimated tolerance values applicable to these cases. Where many types of isotopes are in use, the following values form a provisional guide to permissible contamination:

(a) for atmospheric contamination ... 10^{-5} μc/litre

(b) for water contamination ... ... 0.1 μc/litre

[2]Note that the contributions from internal deposition or skin contamination will be effective 24 hours per day, and seven days per week. Contributions from external sources are limited to the normal work week.

II. PERSONNEL

(a) Selection and Instruction of Personnel

Persons who are naturally neat and careful are preferred workers with radioisotopes. A rigid physical examination should be made of all prospective workers. Careful inspection of the hands and evaluation of possible previous exposure to radiation, are recommended. All individuals employed in radiation work shall be informed in detail of all known dangers involved. They shall be instructed regarding local rules and regulations for protection, and should be expected to observe them in all details. It is particularly important that all users of radioisotopes should be considered as potential full-time users.

(b) Effects of Radiation

Effects of external radiation have been adequately described in the Bureau of Standards Handbooks H-23 and HB-20. When the active materials are deposited in the body, the effects depend upon the site of deposition, the physical half-life, and the biological half-life, which is determined by the elimination rate. The bone-seekers (for example, strontium) will produce effects similar to those found in radium poisoning. Other materials may produce changes in liver or kidney function, and occasionally in other organs. An essential feature of all the effects is that they may not appear until the dangerous material has resided in the body for many years, and irreparable latent damage may have been produced. There usually are no definite clinical symptoms which can be relied upon to guard against possible impending injury.

(c) Blood Count

A complete blood count shall be made by a skilled hematologist before any individual begins work involving the handling of radio-active materials. No one should be employed who shows pertinent abnormalities in the blood count. Blood counts should be made at regular intervals during employment, but more attention given to the trend of successive counts and, especially, of the differential count ratios than to absolute values. It should not be considered that overexposure of the individual *will* be detected by changes in blood

count.[3] Poor protection techniques *may* be detected by blood count findings before permanent injury to the individual occurs.

(d) PHYSICAL EXAMINATIONS

1. *General*

A thorough medical examination should be made of each individual potentially exposed to significant amounts of radiation before employment, and annually thereafter. An examination for possible radioactivity, by a person with special knowledge and equipment, should be given each individual, and form a part of the annual physical examination, whenever the exposure potential includes significant internal deposition. More frequent examinations are warranted when the exposure potential is high. The nature of such tests will depend upon the particular isotopes to which the individual may have been exposed. Sufficiently sensitive tests for the deposition of all relevant isotopes may not exist.

2. *Urinalysis and Other Tests*

An analysis of radioactivity of the urine is a desired procedure. Normal urine contains radio-potassium in amounts which may mask the added radioisotopes for which tests are made. Either potassium should be separated from the sample and the residual activity measured, or when the possible exposure is restricted to one isotope, this should be chemically separated from the urine. Examination of the feces may be required when the predominant elimination is by feces. Special tests for specific isotopes are in order when they exist (e.g., radio-iodine may be estimated in the thyroid gland in terms of the emitted gamma radiation measured by a Geiger counter or ionization chamber). Where exposure to radioisotope dust or spray is a possibility, it may be desirable to test the activity of a nasal smear, or of the sputum.

(e) PERSONAL CLEANLINESS

Radioactive isotopes must be treated like other poisonous substances. Extreme personal cleanliness in the laboratory is, therefore, desired. The material must not be spilled or

[3] A single exposure of 25 r can apparently escape detection by standard blood counting techniques.

scattered, and must not come in contact with the hands or clothing to any appreciable extent. At the end of each work period, the hands shall be carefully washed. No edibles of any kind, including chewing gum, candy or beverages, shall be brought into the laboratories, nor shall they be touched before removing all washable traces of radioisotopes from the hands. The use of cigarettes or the application of cosmetics in the laboratory may result in transference of activity to the lips.

The hands should be tested frequently with a Geiger counter or other suitable instrument to determine whether contamination exists. Immediate steps to remove contamination shall be taken when found.

(f) Housekeeping

Neatness in the laboratory is a prime requisite for elimination of the spread of contamination. The work area should be free from equipment and materials not required for the experiment at hand, and the equipment used should be decontaminated and stored in a controlled location after use.

(g) Supervision

The supervisor of a work group or the leader of a laboratory group has the responsibility for seeing that the radiation work under his guidance is performed in a safe manner. The supervisor is required to see that the established rules regarding food handling, checks of personnel activity, waste disposal, etc., are maintained. The objective is the education of each and every worker to follow the necessary procedures for his own protection, and the protection of others. In a radioisotope laboratory, skill in radiation protection is as necessary as skill in chemical or biological manipulations. Persons failing to develop such skill should be advised to transfer to other occupations.

III. LABORATORY DESIGN AND EQUIPMENT

(a) General Working Conditions

Successful work with radioisotopes other than in true tracer amounts requires the use of laboratories and equipment specially designed for the purpose. No work should be undertaken

in these rooms other than that concerned with the application of radioisotopes.

(b) FLOORS

The floors shall have smooth, continuous surfaces as far as possible such as stainless steel, painted concrete, or linoleum. Absorbent floors, for example, wood, should be avoided. Asphalt, tile and similar materials are permissible, provided that the laboratory supervision is aware of the hazards of accumulation of radioisotopes in the cracks. The ease of replacement of sections of tile floor compensate for the hazard of crack contamination. Floors should be cleaned daily by wet mopping, or by the use of moist compound. Dry-sweeping may lead to an active dust hazard.

(c) WALLS, CEILING, AND WOODWORK

Walls, ceiling, and woodwork shall be finished with non-porous washable surface, which may be cleaned to remove accumulation of radioactivity. Projecting ledges, hanging lamps, etc., which may accumulate dust, should be avoided.

(d) VENTILATION

All laboratory operations with more than low level activity should be conducted in hoods which will be provided with forced ventilation sufficient to maintain the activity content of the room air below 10^{-5} μc/litre at any place at any time. The linear velocity of air flow should be in the range of 100 to 150 ft. per minute. Specially hazardous operations, i.e., handling long-lived bone-seeking isotopes in injection or inhalation studies on animals, should be conducted by personnel wearing suitable respirators or supplied-air masks. Hoods with individual filter systems for the exhaust air are preferred. Multiple hood systems are dangerous because reverse air currents may occur.

(e) EQUIPMENT

Special equipment suitable for the type and level of activity being used should be provided for each type of operation. This should include handling tools such as tongs, forceps, trays and mechanical holders. Long-handled tools provide adequate protection by distance where millicurie amounts of beta or gamma activity are encountered. Semi-remote control sampling and stirring devices should be included. Operations

with larger amounts require the use of specially designed, remote-control equipment including a shielded optical system (e.g., a periscope or mirror arrangement). When the isotopes concerned are primarily beta emitters, efficient use can be made of transparent plastic shields[4] fitting closely around the equipment to allow close handling with good visibility.

Containers for the active material should incorporate the necessary shielding as close to the surface as possible. Containers for liquid samples should always be reinforced by an outer, unbreakable container.

(f) Hoods and Benches

Laboratory benches should be free from cracks, crevices, or sharp corners. Suitable surfaces for work tables are stainless steel, Monel metal and plate glass. The work surface should be covered with an absorbent paper[5] to catch minor spills, and this paper should be changed after each laboratory experiment. The work in hoods should similarly be performed over an inner washable tray covered with the absorbent paper. The work bench should be equipped with wiping papers for the prompt removal of spills. Drawers in work benches, if provided at all, should be washable and have removable liners.

(g) Disposal of Contaminated Wastes

(1) *Absorbent papers, wipes, etc.*

Waterproof disposable containers to hold the discarded absorbent bench paper and wiping papers should be provided at each laboratory station. Regular collections of these disposal vessels from the laboratory should be made.

The eventual disposal of such items is conditioned by the half-life and toxicity level of the isotopes involved. With short half-lives, retention of the materials in a controlled area, until their residual activity is insignificant, is a preferred method. With long-lived isotopes, the laboratory management is committed to a prevention of contamination of the public domain. The association of groups of laboratories to provide a single controlled and economical disposal area may be feasible.

[4] See Appendix 1 for thickness.

[5] A "diaper" paper is available that has a waterproof backing to reduce penetration of spills to the work surface.

(2) *Active Solutions*

The disposal of active solutions to the public sewers can only be considered safe when the possible subsequent chemical, physical and biological concentrations will still leave the material at safe concentrations. Disposal to a water system should include consideration of the accumulation of activity in soil or mud, and in algæ and similar organisms. Concentration of the order of 100,000 fold may occur. Whenever possible, the principal activity in the waste solution should be precipitated, and discarded as active solid material.

Urine from isotope-injected animals or patients, and liquors from equipment or clothing decontamination, may require attention as active solutions.

(3) *Tools*

Tools and other miscellaneous equipment used in handling long-lived isotopes should be regarded as contaminated and should not be released for other work until proven otherwise.

(h) PROTECTIVE CLOTHING

The degree of protection required is a function of the activity used. Even trace amounts should be handled with laboratory coats protecting normal attire. Where routine radiochemical or biological work is done, coveralls restricted to this operation shall be worn. Rubber gloves should be worn while handling active materials which may give rise to contamination of the hands. If the material may be spilled on the floor, special cloth or rubber overshoes should be used. In some cases, the provision of shoes to be used only in the laboratory is preferable.

Good protective practice is similar to, but usually less stringent than that employed in the manipulation of virulent bacteriological organisms.

IV. HAZARD INSTRUMENTATION

(a) PERSONNEL METERS

(1) *Pocket Ion Chambers*

Each radiation worker should wear a pocket ionization chamber throughout the course of his work. The chamber

should be effective in the range up to 200 mr. Daily measurements of the integrated gamma ray dose should be recorded. It has been found preferable in many cases to wear two identical pocket chambers, in which case the lower of the two readings is considered valid. This eliminates casual errors due to accidental discharge of one chamber. The usual chambers are not sensitive to beta radiation. Where the isotopes used do not emit gamma rays, specially constructed beta chambers should be provided.

(2) *Film Badges*

Pocket chambers should be supplemented by a film badge which contains film partially covered by a suitable metallic filter such as one millimetre of silver or cadmium. Blackening of the film in the shielded area is then approximately independent of the energy of the gamma radiation (above 80 Kev.). Blackening of the unshielded portion may be due to beta radiation or gamma radiation, especially low energy gamma radiation. Such film badges give a sufficiently quantitative record of the integrated weekly gamma-ray dose. The beta-ray dose can be obtained quantitatively when exposure to soft gamma radiation is excluded. Special film packets containing two films of different sensitivity are available for badge monitoring. Sensitive film is effective in the range 25 mr to about 5 r. The insensitive film is effective up to about 40 r, and is read only in the event of a major exposure.

(3) *Finger Rings*

Workers who manipulate radioactive solutions or handle sources should wear film rings or other suitable devices on the fingers to estimate the hand exposure. Rings which include the metal shield with open window can be used. In many cases, a simple film disc covered with thin rubber is an effective substitute, which introduces very little inconvenience in handling laboratory tools. Strictly quantitative results are obtained only when calibrations can be made with the particular isotopes used in the laboratory.

(b) BETA-GAMMA SURVEY METERS

These meters fall into two classes:

(1) Sensitive detection instruments primarily used for

qualitative estimation of contamination. Whenever contamination is found, it is customary to remove it, and there is consequently no need to determine the exposure, quantitatively. Geiger counters in various circuit combinations are frequently used for this purpose. The Zeuto survey meter is also convenient for detection purposes.

(2) Quantitative survey meters consisting of ion chambers with suitable indicating circuits, for the measurement of radiation transmitted through shields, or in other cases where it is necessary to evaluate the potential radiation exposure. When properly designed, the response of these chambers is independent of the wavelength of the incident radiation over a wide range. The chambers are made optionally sensitive to both beta and gamma radiations or to gamma radiation only. This is effected by provision of a removable shield over a thin window on the chamber. Table 3 includes some of the currently available radiation meters.

(c) BETA-GAMMA HAND COUNTERS AND SHOE COUNTERS

The small laboratory can use the simple Geiger counter equipment for the detection of contamination on the hands and shoes of the workers. Where the procedure is economically justified, it is preferred to use combinations of G.M. tubes assembled so as to register the activity on both sides of the hands and on the shoes. Ten-tube combinations are available for this purpose. Registration may be either by scaler and registers, or by multiple counting-rate meters. Whenever it is required to make a permanent record of the hand and shoe counts, the scaler-register combination is more effective and can be made on an automatic printing basis.

(d) DUST, GAS, AND VAPOUR SAMPLERS

(1) *Dust Samplers*

Dust or spray may be sampled through drawing air through a filter, or by electrostatic precipitation. The filtration method is reliable, provided that leaks around the edge of the collection paper are eliminated. The activity on the sample paper is measured on standard laboratory counting equipment. Complications are introduced when the half-life of the collected material is short or comparable with the collection time. The electrostatic

precipitation method permits the precipitation on to an aluminium surface which is a suitable source for the evaluation of range and energy of the deposited particles.

(2) *Gas and Vapour Samplers*

One type of sampler draws air through an ion chamber and measures the ion current with a suitable electrometer circuit. A continuous record of the activity in the atmosphere may be obtained in this manner. The method is unsuitable at low levels because of the difficulty of avoiding disturbance to the chamber insulators by friction, etc. Another method involves the collection of samples in evacuated containers which can be returned to a central location for sampling. In special cases, chemical or adsorption methods are available for specific gases or vapours.

V. HAZARD MONITORING

(a) Inspection of Personnel

The monitoring of personnel with respect to incident radiation is achieved by the use of pocket ion chambers and/or film badges worn on the person. It is standard practice to process the pocket chambers daily, and films weekly. Where experience has shown continued low exposure, films read every two weeks give an adequate exposure index. Similarly, self-reading pocket chambers may be worn for an extended period if the casual leakage is insignificant. Finger film should be processed at least weekly.

In general, each individual using radioisotopes should be responsible for monitoring himself against contamination. The inspection should include qualitative tests for contamination of the clothing, hands, and other parts, that may be contaminated. Hand checks shall be mandatory before leaving the work area for lunch or termination of the work day. In those cases where the risk of absorption of the isotopes through an open cut is important, hands should be inspected by the supervisor or laboratory leader at the beginning of the work day, and injured persons excluded from the programme.

Prompt removal of contamination when found is a necessary corollary of the inspection.

Table 3.—Typical Radiation Survey Meters

Instrument	Radiation detected	Description*	Ranges†	Remarks
Lauritsen Electroscope	Beta Gamma	Quartz fiber electroscope Available: Fred C. Henson Co., Pasadena, California.	1 mr per hr. to 1 r per hr.	Incomplete saturation gives non-linear response, requiring specialized calibration. When equipped with thin window and a detachable shield cover (eg., 3 mm. Al) can be used for almost all necessary protection operations in the small laboratory.
L-W (Landsverk- Wollan) Survey Meter	Beta Gamma	Improved quartz fiber electroscope, 100 c.c. ion chamber; timing circuit produces flashes in field of reading microscope. Sliding metal screen to eliminate beta radiation Landsverk Electrometer Co., Chicago, Illinois.	2 Scales Up to 100 mr per hr. and up to 1 r per hr.	Rugged, holds calibration well. Time-consuming, but otherwise convenient and versatile. Satisfactorily free from wavelength dependence.
Victoreen Survey Meter	Gamma	Compact chamber and amplifier circuit. Wide variety of alternative ranges available on special order. Victoreen Instrument Co., Cleveland, Ohio.	Normally up to 120 mr per hr.	Well suited to local modification to operate chamber on a long probe, thus keeping operator's body out of dangerous radiation fields.
Portable Geiger Muller counters	Beta Gamma	Audible signal, or integration by counting-rate meter, or both. Many commercial forms available.	Background to about 80,000 counts per min.	For rapid detection of radiation. Normally improper for quantitative work. Each type should be tested for temperature dependence.
C.P. Meter	Beta Gamma	Chamber 3 ins. diameter by 6 ins. long with detachable end cap for beta-gamma discrimination. Standard electronic circuit. Range switching in vacuo to eliminate extra-cameral ionization. One type available from Sylvania Electric Products Inc., New York, N.Y.	3 Scales Up to 40 mr per hr. 400 mr per hr. 4 r per hr.	Weighs only 4 lb., easily set at zero in presence of radiation. Excellent general-purpose meter for radiation field or surface contamination measurements.

Table 3.—Typical Radiation Survey Meters—Continued

Instrument	Radiation detected	Description*	Ranges†	Remarks
Zeus	Beta Gamma (Alpha)	"Shoe box" type with 1- to 2-liter ion chamber, with wire-mesh window. Thin screen slides in to eliminate alpha radiation, and thick plastic screen further discriminates between beta and gamma rays. Amplifier has favorable time constant. eg: Rauland Corp., Chicago, Illinois.	5 Scales Up to 25 mr per hr. 100 mr per hr. 500 mr per hr. 2.5 per hr. 2.5 r per hr.	Rugged and reliable general-purpose instructions. Not entirely free from wavelength dependence, but this is not a critical defect.
Zeuto	Beta (Alpha)	Similar to Zeus circuit, but with feed-back to increase sensitivity. Designed for alpha measurements, but suitable for beta radiation. eg: Victoreen Instrument Co., Cleveland, Ohio.	2 Scales Up to 4 mrep per hr. Up to 40 mrep per hr.	High sensitivity and fair stability. Good for surface contamination measurements, and can be applied to C^{14} and S^{35} contamination.

* Indication of a manufacturer's name does not constitute endorsement of the instrument, nor deny the superiority of other makes.
† For beta-gamma instruments, the gamma rays are quoted. Calibrations for beta radiation may depend on the energy of the particles and the geometrical distributions of the source.

(b) INSPECTION OF WORK AREAS

The beta- and gamma-ray exposures at points habitually occupied by workers should be determined periodically by properly designed ionization or counter devices, operated by qualified personnel. An instrument, or instruments, should be available to cover the range from 1 mr/hr up to 2 r/hr. Other meters for the qualitative detection of small amounts of active contamination should be available. Under laboratory conditions, each person in the laboratory should be responsible for maintaining an adequate frequency of inspection in his own work area. In larger organizations, it may be expedient to employ personnel specifically for these inspections. Continuous monitoring equipment, which may have an alarm feature, is suitable for locations handling "curie" amounts of radioisotopes. Such meters, and many portable survey meters, give an inadequate indication of the hazard arising from contaminated surfaces. Such surfaces may give a direct contact exposure hazard, or offer a means of transfer to the body.

The instrument response corresponding to a permissible level of beta contamination is a function of the active materials involved, and each laboratory should properly evaluate these levels for its own purpose. In general, if a Geiger counter of flat-plate area about 2 sq. ins. is passed with a normal hand motion over a suspected surface, contamination is present in undesirable amounts if there is an obvious instrument response. This policy will result in the cleaning of some areas which were not specifically dangerous to personnel. This in general is offset by the easier definition of this particular limit, and the benefits arising from the maintenance of an extremely clean work area. Care must be taken to ensure that the test instrument used is reasonably responsive to radiations emitted by the available isotopes (for example, if C^{14} is used, rather specialized search equipment may be necessary).

The amount of activity in the form of gas, vapour, dust or spray in the air has to be determined routinely in the laboratory if the activities used are compatible with the production of an inhalation hazard.

(c) INSPECTION OF PROTECTIVE CLOTHING

The first inspection of protective clothing should be made by the wearer prior to removal. Very active items should be discarded as active solid waste, in closed containers. The

remaining items should be washed and monitored under controlled conditions. Special laundry facilities should be used by all groups regularly engaged in radioisotope work. Preferred solvents for laundry rinses depend on the chemistry of the isotopes used. Where miscellaneous isotopes may be present, dilute acetic acid is recommended. Dilute nitric acid may be used on rubber items. Before contaminated garments are considered for release to public laundry service, the extent of hazard shall be very carefully evaluated.

(d) INSPECTION OF WASTES

Laboratory personnel is responsible for the inspection of the disposable containers for solid waste. Tests for emitted beta and gamma radiation, and in some cases for radioactive contamination of surrounding air, are required. Radiation monitoring of the assembly of these containers at a central depot may be necessary.

Monitoring and segregation of active liquid waste is similarly required. The inspection of gaseous and dust effluents, etc., is mandatory in the larger installations where such effluents may be hazardous. Tests for possible deposition and accumulation beyond the confines of the laboratory may be required. Detection methods sufficiently sensitive to give large scale-deflections when subjected to natural radioactive contamination in air, water, or soil, are required, because the maximum permissible additional contamination is of this same order of magnitude.

(e) MANAGEMENT OF RADIATION ACCIDENTS

1. *External Radiation*

   A person presumed significantly over-exposed to external radiation should be removed promptly from the hazardous area. Such a person should not be allowed to return to work involving radiation unless it is evident that radiation damage will not result. If investigation indicates that the over-exposure may be serious, the exposed person should be referred to a physician, qualified to ascertain the extent of the radiation injury, if any.

2. *Ingestion*

   Persons swallowing radioactive solutions should be treated as for poisoning. The material should be removed by an emetic or by stomach pump, and the residue rendered insoluble to reduce absorption. Addition of

carrier element may be indicated. Blood samples and subsequent urine samples should be analysed to compute the body content of contaminant. Where this approximates the maximum permissible load, radical corrective procedures are indicated. Similar protocol applies to other forms of potential intake described below.

3. *Surface Contamination*

Persons splashed with active solutions should wash the affected parts immediately, and, if still contaminated, apply recognized decontaminating agents. Where the chemistry of the active solution is not immediately known, an application of titanium dioxide paste, or a saturated solution of potassium permanganate followed by a 5 per cent. sodium bisulfite solution rinse, is frequently effective. Care should be taken to ensure that no activity is left under the finger-nails.

When the hand is known to be contaminated with a small spot of high specific activity, it is better not to wash the hand, as this unnecessarily spreads the contamination. Such spots are removed by masking off the surrounding areas, and by cleaning the affected part with cotton applicators dipped in suitable decontaminants.

4. *Minor Injuries*

Persons cut by glassware, injured by hypodermic needles, etc., should wash the injured part under a strong stream of water. A venous-return tourniquet may be applied if the material is unusually toxic. If it is ascertained that the injury was caused by an item bearing a hazardous amount of material, a biopsy section of the wound should be analysed. Excision of the part to reduce further body absorption may be indicated in extreme cases.

5. *Inhalation*

Persons inhaling radio-toxic fume, spray, or dust, should be treated to stimulate removal of the toxic material from the lung.

VI. TRANSPORTATION

(a) Shipment of Isotopes

The shipment of radioisotopes should be made in accordance with the regulations of the Interstate Commerce

Commission, and with any further specific restrictions of authorized distributors of radioactive material. (See Appendix 3.) The formal regulations cover interstate rail, truck and water transportation. Transportation by air operates under an interim arrangement. (See Appendix 3.)

(b) MOVEMENTS IN THE LABORATORY

Each laboratory or institution should have a central controlled storage location for incoming isotope shipments. The minimum amounts of active material necessary for the intended processing should be withdrawn from this store, and any excess returned promptly after the operation. Movements of millecurie or greater amounts should be governed by written transfers. Each laboratory supervisor is then aware of the total activity problem in his group. Transfers from the central store to each laboratory should be made in properly shielded containers, and liquid shipments should be protected against spills. Within the laboratory, the active material shall be kept in a specified safe work place. Transfers from one place to another should be reduced to a minimum, and when necessary should be made with shielding adequate to protect all personnel in the laboratory. The general rules for such shielding may be deduced from the regulations prescribed for the shipment of isotopes outside the laboratory. (See Appendices 2 and 3.)

Appendix 1

BETA-RAY SHIELDING

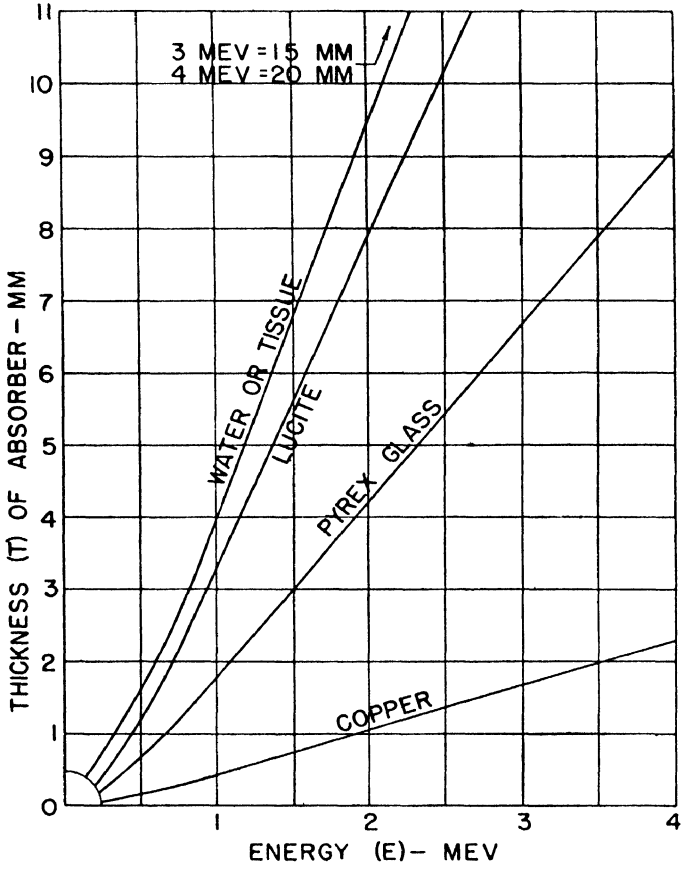


Fig. 3.—Thickness, T MM, of typical materials required to stop completely beta-rays of maximum energy, E Mev.

Appendix 2

A GAMMA RAY SHIELDING TABLE
SHIELD THICKNESS FOR LABORATORY SOURCES

Select column for energy required (use next higher if exact value is not given). Entry gives thickness in cm Pb for different source strengths at 1 meter for 8 hrs./day to give 100 mr. *Add* algebraically the correction terms for other working ranges or times, and *multiply* by factor for shield material.

Example: An iron shield is required for the manipulation of 500 mc of radioactive material emitting 1.8 Mev gamma rays at a minimum working distance of 50 cm, and for two hours per day.

Shield thickness = (7.08 [*basic entry*] + 2.76 [*correction for danger range = 50 cm*] − 2.70 [*correction for 2 hrs/day*]) × 1.53 cm Fe [*conversion from Pb to Fe*] = 10.9 cm Fe.

NOTES

(1) Source activity is quoted in millicuries or curies, where 1 curie is that amount of radioactive material that disintegrates at the rate of 3.7×10^{10} dis. per sec. However, the table is computed on the further assumption that each disintegration yields one gamma photon of the selected energy. This will lead to inaccuracies whenever the disintegration is complex. More accurate calculations can be made by obvious methods when the disintegration scheme is known.

(2) The tabulation ignores the increased effective transmission of shields under wide beam irradiation.

(3) This form of shielding table (prepared by C. C. Gamertsfelder) is intended to form a guide to rapid erection of temporary shielding structures in the laboratory. Where permanent installations of maximum economy are planned, more detailed calculations by conventional methods are required.

(4) Where it is preferred to operate in terms of source strength stated in roentgens per hour at 1 meter (rhm) the small table on page 117 showing conversion to conventional curies, as used above, is made.

Activity	0.2 Mev	0.5 Mev	0.8 Mev	1 Mev	1.5 Mev	2 Mev	2.5 Mev	3 Mev	4 Mev
10 mc ..	− .50	− .86	−1.02	− 1.05	− .83	− .61	− .39	− .13	− .23
20 mc ..	− .36	− .44	− .33	− .14	+ .33	+ .76	+ 1.06	+ 1.36	+ 1.68
50 mc ..	− .17	+ .09	+ .59	+ 1.04	+ 1.82	+ 2.55	+ 2.95	+ 3.30	+ 3.58
100 mc ..	− .03	+ .33	+1.28	+ 1.95	+ 2.97	+ 3.92	+ 4.41	+ 4.79	+ 5.03
200 mc ..	+ .10	+ .91	+1.97	+ 2.85	+ 4.11	+ 5.27	+ 5.84	+ 6.26	+ 6.47
500 mc ..	+ .30	+1.46	+2.89	+ 4.04	+ 5.61	+ 7.08	+ 7.76	+ 8.22	+ 8.38
1 c ..	+ .42	+1.86	+3.57	+ 4.94	+ 6.75	+ 8.43	+ 9.19	+ 9.69	+ 9.82
2 c ..	+ .56	+2.27	+4.27	+ 5.84	+ 7.87	+ 9.78	+10.63	+11.16	+11.25
5 c ..	+ .75	+2.81	+5.19	+ 7.03	+ 9.39	+11.58	+12.54	+13.12	+13.17
10 c ..	+ .89	+3.22	+5.87	+ 7.94	+10.52	+12.94	+13.98	+14.59	+14.60
20 c ..	+1.03	+3.63	+6.57	+ 8.84	+11.67	+14.31	+15.43	+16.08	+16.06
50 c ..	+1.21	+4.17	+7.47	+10.02	+13.16	+16.09	+17.33	+18.02	+17.95
100 c ..	+1.35	+4.58	+8.18	+10.93	+14.31	+17.46	+18.78	+19.51	+19.41
Danger range	plus	plus	plus	plus	plus	plus	plus	plus	plus
20 cm ..	+ .64	+1.90	+3.22	+ 4.19	+ 5.28	+ 6.31	+ 6.70	+ 8.68	+ 6.70
50 cm ..	+ .28	+ .83	+1.39	+ 1.83	+ 2.32	+ 2.76	+ 2.93	+ 3.00	+ 2.93
1 m ..	.00	.00	.00	.00	.00	.00	.00	.00	.00
2 m ..	+ .28	− .83	−1.39	− 1.83	− 2.32	− 2.76	− 2.93	− 3.00	− 2.93
5 m ..	− .64	−1.90	−3.22	− 4.19	− 5.28	− 6.31	− 6.70	− 8.68	− 6.70
10 m ..	− .92	−2.71	−4.60	− 5.98	− 7.55	− 9.02	− 9.57	− 9.80	− 9.57
Working time	plus	plus	plus	plus	plus	plus	plus	plus	plus
1-hr. day ..	− .41	−1.22	−2.08	− 2.69	− 3.40	− 4.06	− 4.31	− 4.41	− 4.31
2-hr. day ..	− .28	− .81	−1.37	− 1.79	− 2.26	− 2.70	− 2.87	− 2.94	− 2.87

Working time—contd.	plus	plus	plus	plus	plus	plus	plus	plus	plus
4-hr. day..	− .14	− .14	− .69	− .90	− 1.14	− 1.35	− 1.44	− 1.47	− 1.44
8-hr. day..	.00	.00	.00	.00	.00	.00	.00	.00	.00
24-hr. day..	+ .18	+ .52	+1.10	+ 1.17	+ 1.48	+ 1.76	+ 1.87	+ 1.92	+ 1.87
Absorber	times	times	times	times	times	times	times	times	times
Pb	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fe	4.75	2.68	2.11	1.75	1.51	1.53	1.53	1.53	1.77
Al*	17.23	7.71	5.43	5.13	4.70	4.25	4.81	5.22	6.01
H_2O	35.00	17.80	12.50	11.15	9.93	10.00	11.20	12.35	14.13

* Or concrete.

Energy (Mev)

	0.2	0.5	0.8	1	1.5	2	3	4
Conventional curie equivalent of 1 rhm	20c	3.4c	2.2c	1.8c	1.3c	1.1c	850mc	710mc

Appendix 3

SHIPPING RULES

STATUS:

The Interstate Commerce Commission requested the Bureau of Explosives, Association of American Railroads to formulate regulations for adoption. The Bureau was assisted by the Subcommittee on Shipment of Radioactive Substances of the Committee on Nuclear Sciences of the National Research Council. The regulations are to become effective January 21, 1948. The following is an excerpt of those rules that will apply to expected shipments of radioisotopes.

MAXIMUM LIMITS OF SHIPMENTS

Not more than two curies of radium, polonium, or other members of the radium family and not more than 10^{11} disintegrations per second of all other radioactive materials may be packed in one outside container for shipment by rail express except by special arrangements and under conditions approved by the Bureau of Explosives.

EXEMPTIONS FROM PACKING, LABELLING AND MARKING REQUIREMENTS

Radioactive materials are exempted from prescribed packing requirements provided they fulfil all of the following conditions:—

(1) The package must be such that there can be no leakage of radioactive materials under conditions normally incident to transportation.

(2) The package must not contain more than 0.1 millicurie of members of the radium family or the equivalent amount of plutonium, and not more than 5×10^6 disintegrations per second of strontium 89, strontium 90, or barium 140, or 50×10^6 disintegrations per second of any other substance.

(3) The package must be such that no significant alpha or beta radiation is emitted from the exterior of the package, and the gamma radiation at any surface of the package must be less than the equivalent of 10 milliroentgens of radium gamma radiation filtered through $\frac{1}{2}$ inch of lead in 24 hours.

PACKAGING AND SHIELDING

Special Hazards:—Radioactive materials which present special hazards due to their tendency to remain fixed in the human body for long periods of time (i.e., radium, plutonium, strontium) must, in addition to the packing described below, be packed in inside metal containers, specification 2R, or other containers approved by the Bureau of Explosives. Quantities and materials considered under this heading will be determined by the Bureau of Explosives.

Packaging and Shieldings:—

(1) All radioactive materials must be so packed and shielded that the degree of fogging of undeveloped photographic film under conditions normally incident to transportation (24 hours at 15 ft. from the package) will not exceed that produced by 11.5 milliroentgens of radium gamma rays filtered by $\frac{1}{2}$ inch of lead.

(2) The design and preparation of the package must be such that there will be no significant radioactive surface contamination on any part of the container.

(3) The smallest dimensions of any outside shipping container for radioactive materials must not be less than 4 inches.

(4) All outside shipping containers must be of such design that the gamma radiation will not exceed 200 milliroentgens per hour or equivalent at any point of readily accessible surface. Containers must be equipped with handles and protective devices when necessary in order to satisfy this requirement.

(5) The outside of the shipping container for any radioactive material, unless specifically exempt from packaging requirements, must be a wooden box, Specification 15A or 15B, or a fibreboard box, Specification 12B (Bureau of Explosives), except that equally efficient containers may be used when approved by the Bureau of Explosives.

(6) Radioactive materials which emit gamma rays must be packed in suitable inside containers completely surrounded by a shield of lead or other suitable material of such thickness that at any time during transportation the gamma radiation at one meter from any point on the radioactive sources will not exceed 10 milliroentgens per hour for hard gamma rays, or that amount of radiation which will have the same effect on film as 10 mr per hour of radium gamma rays filtered through one $\frac{1}{2}$ inch of lead.

The shield must be so designed that it will not open or break under conditions normally incident to transportation, and must be sufficient to prevent the escape to the exterior of the outside shipping container of any corpuscular electrically charged radiation.

(7) Radioactive materials which emit only corpuscular electrically charged particles must be packaged in suitable inside containers completely shielded so that at any time during transportation the radiation measured from any point on the shipping container will not exceed the following limits:—

(a) 10 milliroentgens per hour for hard gamma rays, or that amount of radiation which wil have the same effect on film as 10 milliroentgens per hour of radium gamma rays filtered through ½ inch of lead,
(b) Electrically charged corpuscular radiation which has the same physiological effect as 10 milliroentgens per hour of gamma rays.

When more than one type of the above radiations is present, the radiation of each type must be reduced by shielding so that the total emission does not exceed that of paragraphs (a) and (b). The shielding must be designed so as to maintain its efficiency under conditions normally incident to transportation.

(8) Liquid Radioactive Materials must, in addition, be packed in tight glass, earthenware, or other suitable inside containers. The inside container must be surrounded on all sides and within the shield by an absorbent material sufficient to absorb the entire liquid contents and of such nature that its efficiency will not be impaired by chemical reaction with the contents. If the container is packaged in a metal container, Specification 2R, or other container approved by the Bureau of Explosives, the absorbent cushioning is not required.

(9) Radioactive materials emitting electrically charged particles only must be packed in suitable inside containers completely wrapped and/or shielded with such material as will prevent the escape of primary corpuscular radiation to the exterior of the shipping container, and the secondary radiation at the surface must not exceed the equivalent of 10 milliroentgens of radium gamma rays filtered through ½ inch of lead in 24 hours.

(10) Empty Shipping Containers: All containers and accessories which have been used in shipments of radioactive materials, when shipped as empty containers, must be sufficiently free from radioactive contamination, that there is no significant alpha or beta radiation[6] at the surface, and the gamma radiation at any surface shall be less than 10 milliroentgens for 24 hours.

Labelling and Marking of Packages

Each outside container of radioactive material, which emits gamma rays or gamma rays plus electrically charged corpuscular rays unless specifically exempt, must be labelled with a label, red letters on white background, with design and wording as prescribed by the Bureau of Explosives. Each outside container of radioactive material, which emits corpuscular electrically charged particles only must, unless specifically exempt, be labelled with a label, blue letters on white background, as prescribed.

Shipment of Radioactive Materials by Air

An interim arrangement, under which air express shipments of radioactive substances are currently carried by certain air lines, is given in Rule 13-A of Supplement 5 to the Railway Express Agency, Air Express Division, Tariff 8. This document is also known as Supplement 5 to CAB 22— It reads in part:—

> The following radioactive materials will be accepted, subject to shipper compliance with the following requirements, except that such shipments will not be accepted for transportation in aircraft operated by All American Aviation, Inc., Inland Air Lines, Inc., National Airlines, Inc., Northwest Airlines, Inc., Transcontinental and Western Air, Inc., and/or Western Air Lines, Inc. (See Rule 12-8.)
>
> Characteristics: Emit Gamma and other rays with maximum rating for one gram equivalent of radium.

[6] By " significant " radiation is meant about 500 alpha disintegrations per 100 cm.^{2} per minute, or about 0.1 mrep/hour of beta radiation.

Protective Packaging Required: Encasement in lead of thickness prescribed by "Committee on Standards of Radioactivity—National Research Council" for full protection of undeveloped films at 30 ft. (developed films unaffected) and full protection of all air line personnel and passengers.

Special Marking on Package Required: "Do not place in same compartment with undeveloped films or mail."

Appendix 4

PARTIAL LIST OF RECENT PUBLICATIONS OF INTEREST TO RADIOISOTOPE LABORATORIES

1. Atomic Energy Commission, Isotopes Division, Circular B-1, General Rules and Procedures Concerning Radioactive Hazards.
2. Cantril, S. T., Safety Rules and Procedures Concerning Activity Hazards, MDDC 992.
3. Cantril, S. T., and Parker, H. M., The Tolerance Dose MDCC 1100.
4. Levy, H. A., Some Aspects of the Design of Radiochemical Laboratories, Chem. and Eng. News, 24, 3168, 1946.
5. Morgan, K. Z., The Responsibilties of Health Physics, Scientific Monthly 63, 93, 1946.
6. Morgan K. Z., Tolerance Concentrations of Radioactive Substances, J. Phys. and Colloid Chem. 51, 894, 1947.
7. Morgan, K. Z., Health Physics and its Control of Radiation Exposures at Clinton Laboratories, Chem. and Eng. News, Dec., 1947.
8. Pardue, L. A., Goldstein, N., and Wollan, E. O., Photographic Film as a Pocket Radiation Dosimeter, MDDC 1065.
9. Parker, H. M., Radiation Hazards of Bremsstrahlung, MDDC 1012.
10. Parker, H. M., Health Physics, Instrumentation and Radiation Protection MDDC 783.
11. Sullivan, W. H., Control of Radioactive Hazards, Chem. and Eng. News, 25, 1862, 1947.
12. Tompkins, P. C., Laboratory Handling of Radioactive Materials in Experimental Biology, MDDC 377.
13. Wirth, J. E., Occupational Med. 2, 428, 1946.

CHAPTER X

HUMAN WELFARE AND ISOTOPES

MAN'S conquest of nature has generally followed the pattern of (a) observation, (b) understanding, and (c) control. The microscope and the X-ray machine have brought into view the cells and organs of living bodies, the molecules and crystalline structure of matter. But until recently, man's vision has not penetrated into the details of growth and change in the living cell or the intricate chemistry of the molecule.

All told, the 96 chemical elements have more than 800 isotopes, stable and radioactive. Carbon, for example, has five isotopes giving five kinds of carbon atom, chemically indentical but having mass numbers 10, 11, 12, 13 and 14. Of these 12 and 13 are natural and stable, the others being man-made and radioactive.

Quite minute amounts of the radioactive isotopes can be readily detected by sensitive electrical instruments. For example, in a radioisotopic unit weighing one thousandth of an ounce with a standard activity of one millicurie, we have approximately 37 million atoms disintegrating *per second.*

Generally speaking, the signals sent out by radioisotopes can be readily distinguished one from another. The radiation from C.11, for example, is very penetrating or "hard," that from C.14, very "soft." The intensity of the radiation of a given element, depending on the rate at which its atoms transform into the stable state, is directly related to its "half-life," that is the period in which the radioactivity decreases to one-half its original value. The half-lives of the elements are determined by their nuclear structure, and nothing that man does can lengthen or shorten them by as much as an instant. C.11, with its intense radiation, has a half-life of 21 minutes. C.14, on the other hand, has a half-life of 5,100 years. Most half-lives of the radioisotopes lie between these extremes, although a few, like that of C.10 (nine seconds), are so short as to be of no practical use as research tools.

The half-life of sodium 24, a radioisotope widely used for medical research and diagnosis, is 14 hours 48 minutes; within that time half its atoms will have transmuted themselves into a stable isotope of magnesium and half of the activity will have been dissipated; in 29 hours 36 minutes, three-quarters

of the radiosodium will be gone. Potassium 42, also widely used, has a similar half-life. Shipments of such isotopes must be scheduled in advance with airlines and other carriers, and customers notified of the hour of delivery.

The penetrating radiation is the other important factor governing despatch and transport of radioisotopes, and units are normally shipped in specially constructed containers, which range in weight from less than a pound to a ton, depending on the thickness of the lead shielding required to stop the radiation. Isotopes such as carbon 14, phosphorus 32 and sulfur 35, can be packed in light containers. Sodium 24, cobalt 60 and iodine 131, on the other hand, require heavy containers, the average weighing between 100 and 150 pounds. The latter type of radioisotope, in its glass or aluminium can, is placed in a steel container which in turn is surrounded by a lead shield, supported firmly inside a stout wooden crate. After packing, the box is checked with a sensitive detecting instrument, and if radiation reaching the outside is still above the tolerance limit, the consignment is repacked with a heavier shield.

No such precautions are needed with the stable isotopes, of which five can now be produced by physico-chemical methods and are therefore available in relatively liberal supply. Hydrogen 2 (deuterium), boron 12, and oxygen 18 are obtainable through the A.E.C. Isotopes Division at Oak Ridge. Carbon 13 and nitrogen 15 are available from the Eastman Kodak Co., Rochester, N.Y. The Sun Oil Company, of Marcus Hook, Pa., has announced its intention of supplying carbon 13 and oxygen 18. In Canada and Great Britain, isotopes are supplied exclusively by the Government establishments at Chalk River and Harwell, respectively.

British research with pile-produced isotopes is branching widely and rapidly in biology and medicine. During 1947 isotopes were obtained under the generous scheme initiated by the United States A.E.C. for the international use of their irradiated materials for therapeutic research. As a result British investigators were able to attack a wide range of urgent medical problems, including:—

General body metabolism, normal and abnormal.

Blood formation, blood volume and circulation in anæmia and other diseases.

Bone formation and bone diseases.

Nerve and muscle metabolism and function.

Normal and abnormal functioning of the brain.
Fetal metabolism and circulation through the placenta.
Influence of pregnancy on metabolism.
Distribution of phosphorus in the teeth.
Flow of fluid into the eye.
Thyroid gland activity, normal and abnormal.
Growth and nutrition of tumours; differentiation between malignant and normal tissue.
Action in the body of immunization agents, and antigens; of enzymes, hormones, and other secretions; of bacteria and virus infections, of penicillin and other drugs.

There research to be done, that some form of international medical is indeed such a vast programme of urgent and vital co-ordination and co-operation is essential to avoid duplication. Many of the investigations demand technical skill and equipment of a very high order, and provided a researcher makes certain that his results are *reproducible*, it is sheer waste of valuable time and effort to have the same work duplicated in another laboratory in some other part of the globe.

For this reason, it is hoped that as early as possible an *international* research programme will be developed and published at reasonable intervals, showing what line of medical research is being followed in isotope laboratories throughout the world, what results are being achieved, and an indication of future programmes. Only by some such means can a serious amount of overlapping and duplication be avoided.

Tracing life processes by the use of stable and radioactive isotopes, we have now learned that all components of the body—the muscles, bones and teeth as well as the blood, secretions and food stores—are in a constant state of breaking down and renewal. The multitude of life compounds involved in this process go through continuous and rapid chemical reactions, many of them reversible. Those not serving at any given moment as part of the fixed structure, and not excreted from the body, are combined into a metabolic " pool " of life ingredients available for use anywhere in the body.

The most surprising fact revealed has been the extreme rapidity with which life processes take place. Experiments with radiosodium provide a measure of their speed. By " tagging " salt (sodium chloride) with sodium 24 and injecting it into the human body, investigators have found that salt is diffused through the walls of the veins, transported to

the sweat glands, converted into sweat, and carried to the surface of the body, all in less than one minute's time. Again, it has been discovered that the transfer of fluid in and out of the human veins is so rapid and continuous that it carries back and forth with it 50 pounds of salt, on the average, every day.

Rapid as they are, however, the biochemical reactions which build up and break down living tissue are so delicately regulated that every part maintains its characteristic form and composition, every fluid its particular chemical make-up; and the total volume of all bodily ingredients remains constant. Although metabolic changes are continuous everywhere, the parts of the body, in health, always appear the same. Hence the classic concept of the body as a mechanical engine.

A modern tracer investigator has compared the body, instead, to a military regiment, which retains its size, form, and composition while the individuals of which its composed are continually changing: joining up, being transferred from post to post, promoted, or demoted; acting as reserves; and finally departing after varying lengths of service.

Since the treatment of illness must be based upon an understanding of the normal functioning of the body, the medical implications of the new concept of the "dynamic state of body constituents" are nothing less than revolutionary. Fundamental changes in medical science are certain to result from research with isotopes. But isotopes assist the medical research scientist and the physician in more immediate ways as well. They are the most powerful and searching laboratory tools yet devised for the investigation of the functioning and malfunctioning of particular organs; for studying the action of vitamins, hormones, enzymes, and other bio-chemical substances; and for testing the efficiency of many kinds of treatments. Furthermore, they are of practical assistance in hospitals for diagnosis and therapy.

Virtually no observation was possible of the mechanisms, reactions, and pathways of elements and compounds in the body before isotopes were available to trace them. The hundreds of different life materials—those built into the structural parts and those in the metabolic "pool"—are indistinguishable as to origin. The almost limitless variations of the basic carbohydrates, fats, and proteins are formed out of relatively few source elements in the diet—carbon nitrogen, hydrogen, oxygen, phosphorus, sulfur, and iodine. Long before

[U.S Army photograph.

Radio-active fertilizer being loaded on the endless belt of the hoppers of a fertilizer distributor. The operator on the left holds an instrument to check the amount of radio-activity

isotopes were available, biologists had attempted to trace some of these elements by labelling them with benzine derivatives, dyes, and other identifiable materials, but the very abnormality of the substances used upset the delicate processes being studied and therefore produced confusing results.

To-day isotopes provide labels for all the fundamental life elements—labels which the body cannot distingush from the normal material. Biologists have already used them to trace such a variety of bodily ingredients as: alcohols, amino acids, antigens, bacteria, bile acids, blood cells, carbohydrates, carcinogens, enzymes, fats, fatty acids, hormones, insulin, nucleic acids, penicillin, pharmaceutical agents, proteins, starches, sulfa drugs, tissue fluids and salts, viruses, and vitamins.

So small are the quantities of radioisotopes required for tracer experiments that most of them can safely be employed in normal human bodies. Calcium 45 and strontium 89 and 90, because they have long half-lives and tend to remain in the body, are at present important exceptions.

Isotopic tracers permit two kinds of biological analysis: qualitative, in which a particular element introduced into an experimental animal, and sometimes a human subject, may be followed wherever it goes, whatever chemical form it takes, and quantitative, in which the amount of the tagged element in a tissue or fluid may be measured with unprecedented delicacy. When these two methods are combined, formerly insoluble biological problems, such as the rate of turnover of nutrient materials in different kinds of cells, may be successfully tackled.

One example may be chosen to illustrate in more detail the advantages offered by radiometrical analysis. The biochemical events which take place in man are of the greatest importance to him, yet they are the hardest to get at because of the difficulty in procuring material for analysis. The biochemist cannot take a sample of thyroid from a man with the same abandon as he can from a dog. To make matters worse, the amount of iodine (this being the element sought) in a piece of thyroid tissue may be extremely small and thus difficult to isolate and measure by chemical means. Finally, taking a gland or a portion of it for analysis, even from an animal, means surgery, interference with the organism and the end of the tissue in question as a functioning entity; that is, only one analysis may be made and the investigator

cannot follow the iodine content of the thyroid as a function of time.

Radioactive iodine has the advantage of sensitivity previously mentioned. Secondly, the radiation from the iodine penetrates to the outside of the body and may be detected by instruments placed on appropriate parts of the anatomy (on the front of the neck for a thyroid measurement). Thirdly, the rate at which the radioiodine enters and leaves the gland in question may be followed continuously since no surgical removal of it is required for measurement. A measurement of the rate of iodine uptake by thyroid tissue in humans was not possible before the manufacture of radioactive iodine. Once available and used for such measurements, results were obtained which led directly into a method of using the same material (in large amounts) as a therapeutic agent in exophthalmic goiter, in addition to use of smaller quantities for the diagnosis of thyroid ailments.

One example may be amplified in order to demonstrate the power of the tracer method to settle problems not otherwise approachable. Mammalian red cells, which are suspended in the plasma of the circulating blood, are the agency for carrying oxygen from the lungs to the cells of all the tissues of the body. The salt concentrations within those cells are markedly influenced during this process and there is much shifting of chloride and bicarbonate ions during each cycle of respiration. Yet the sodium and potassium ion concentrations do *not* change; more peculiar are the sodium and potassium concentrations inside and outside the cell, since the obvious permeability to the negative ions, to sugar and to water would lead to the expectation of permeability to salts. In humans, for example, the sodium concentration *outside* the erythrocyte is about twenty times that inside it, while the concentration of potassium ion inside is about twenty times that outside in the plasma. Potassium and sodium ions are nearly the same, chemically; therefore, how are the inequalities in concentration maintained in the face of the constant shifting of oxygen, carbon dioxide, water, and chloride ions in and out of the cells?

Current theory maintained that these cells, and those of the tissues as well, possessed a selective impermeability to cations. In this way, once a cell was born with its peculiar internal sodium and potassium concentration, it could maintain this in the face of plasma competition by simply not exchanging

cations back and forth across its surface. This hypothesis could not be directly tested. One might hope to raise the sodium concentration on the outside and look for a compensatory rise (or lack of same) inside as proof of permeation (or the reverse), but the sensitivity of these living cells to their environment precluded such an experiment.

Here, then, is the ideal problem for the tracer technique. One has the same salt in two compartments; the question to be settled is, is there exchange of salt between these compartments? To settle this, a small amount of sodium chloride, too small to raise the sodium concentration (but containing sufficient radioactive sodium) was added to the blood and samples were drawn from time to time so that any penetration into the cells could be measured. It was found that radioactive sodium penetrated the cells and eventually assumed the same ratio in and out as the pre-existing sodium had had. This proved conclusively that there is continuous exchange of cations across the red cell wall; the theory which postulates an impermeability to preserve the discrepant ratios must be abandoned and a new mechanism sought. When this is done, we shall know more about the life processes of all the cells in our bodies.

Although it is but one of the many atomic species which make up living matter, carbon occupies a unique position because of the enormous number of compounds it can form. All animal life derives its energy—as well as the structural and functional components of all tissues except bone—from the carbon compounds of plants. These in turn are capable of taking carbon dioxide, discarded by animals as the waste-product of energy consumption, and resynthesizing it into energy-containing compounds available again for animal consumption. The energy required, which is therefore the energy consumed by all animal life, is derived from sunlight. This process is known as photo-synthesis: synthesis under the influence of light. Hence all man's working energy is derived from the sun through a synthetic process involving carbon. It is, therefore, of fundamental importance to man to understand how this is accomplished.

The attack on the problem of photo-synthesis, upon its reverse—carbohydrate utilization in animals—has already been begun with radiocarbon. Whether or not man will ever unravel the mechanism of photo-synthesis and, subsequently, reproduce it at will is not to be predicted here. Suffice it to

say that, if he does, investigations with carbon tracer will be an integral and essential link in his progress. Several years ago, a long-lived carbon isotope known as C-14 was produced for the first time in the cyclotron. This material is a most valuable tool for the attack on photo-synthesis and the entire problem of organic synthesis. The importance of a continuing large supply of this material for research is so great that the existence and operation of chain-reacting piles could be justified for C-14 production alone. It is entirely within the realm of possibility that discoveries made in researches with C-14 may be as important and far-reaching as the discovery of fission itself.

CHAPTER XI

MEDICAL RESEARCH: LABORATORY REPORTS ON APPLICATIONS OF ISOTOPES

University of California, Berkeley, Calif.

RADIOSOLFUR (S35) and radiocarbon (C14) have been used to study the persistence of protein formation and breakdown in the whole animal and its isolated tissues. In the whole animal it is possible to obtain indications of this formation and breakdown, but in its isolated tissues isotopic amino acids provide the only reliable indication of such processes. Consequently, complete reliance is placed on the isotopic technique. After studying the normal picture, we are becoming more concerned with the effects of deviations from the normal resulting from effects of other amino acids, starvation, hormones, etc., on the system. When the picture is more complete we hope to have attained a better conception of protein metabolism.

Amino acids in the body proteins can be formed from the transformation of other amino acids and even from non-amino acid compounds such as carbohydrate and fatty acid. The problem of the mechanism of protein synthesis can only be adequately studied by the labelling techniques with isotopes.

The following results of outstanding interest have been secured:—

1. Amino acids can be incorporated by enzymatic reaction into the fragments of disintegrated cells as long as these fragments can utilize oxygen. This discovery gives hope of determining and purifying the anzymatic components necessary for the synthesis of proteins.
2. Rapidly growing cancerous tissue is able to secure a disproportionate share of the available nutriments and thus tends to starve the normal tissues of the body.

Radioiodine (I 131) is being used in studies of thyroxine synthesis by the thyroid gland and, in general, the mechanism of action of the thyroid gland in health and disease.

Radiophosphorus (P 32) is being used in studies of phospholipid metabolism, namely, to determine the site of origin of this lipid in plasma, its fate in tissue, etc.

Radiocarbon (C 14) is being used in the synthesis of palmitic acid and glucose; the metabolism of both are being followed in the normal and diabetic animal.

Radioactive isotopes of yttrium, columbium, and zirconium have been used in the study of the localization of radioactive isotopes in certain specific animal tissues and organs, both for the purpose of studying the biological effects of special tissue irradiation and for the therapeutic value of such localized irradiation with such isotopes.

Radioarsenic (As 74) has been used in distribution studies in animals that have developed an immunity to arsenic and to determine paths of excretion in the dog.

Radiocarbon (C 14) has been used to study the distribution and excretion of methadon and other morphine substitutes in mice and rats and the relationship of tissue levels to pharmacologic activity.

California Institute of Technology, Pasadena, Calif.

As part of a study of protein and peptide metabolism, lysine was synthesized with radiocarbon (C 14). It has been found that one-thousandth of a milligram of lysine is converted to alpha-aminoadipic acid per 10 milligrams (dry weight) of guinea pig liver homogenate per hour.

In another investigation it had been shown that arginine may be synthesized by the transfer of the amino group of glutamic or aspartic acid to citrulline. Since lysine was also active, it was suggested at the time that it was first converted to glutamic acid which then aminated citrulline. However, experiments in liver homogenate with lysine labelled with C 14 showed that a radioactive dicarboxylic acid was formed. This excluded glutamic acid formation by oxidative removal of the radioactive carbon. Alpha-aminoadipic acid has now been shown to be very probably the product of the reaction.

We are using radiocarbon (C 14) as a tracer in studying the mechanism of protein synthesis in biological materials. This work would be impossible without some such tracer as C 14. As protein is one of the major components of all its catalysts and many of its hormones, as well as in structural tissues, the value of getting some information on the mechanism of its production in the tissue is obvious.

We have so far been able to work out the major steps in

the metabolism of the essential amino acid, lysine, and have also isolated a number of peptides which appear to be intermediate in both the synthesis and degradation of proteins in tissues.

The present programme involves the study of exchange reactions between carbon 14 labelled leucine and antibody globulins. It has been found that such proteins will incorporate the labelled leucine in the body and also in the test tube providing a suitable enzyme system is present. Such studies have also given information as to the rate of antibody formation and the amount of stored or reserve antibody. The in vivo exchange reactions do not take place with foreign proteins, e.g., horse globulins injected into rabbits containing labelled leucine.

Such studies of the formation, destruction and state of serum proteins in the body would, of course, be impossible without the aid of isotopes for tagging definite molecular structures. The C 14 isotope is one of the most valuable for this work.

Carnegie Institution of Washington, Washington, D.C.

Radioiron (Fe 59) has permitted discovery of a method by which fetal iron is derived from maternal plasma. In contrast to the classical conception of the destruction of the red blood cell, it has been learned that ferric beta globulinate of the plasma is a sufficient source of fetal iron for growth.

Use of Fe 59 has led to the elaboration of a method permitting accurate and precise biological assay of extremely small quantities of this substance.

The rate of escape from the plasma of Fe 59 in the form of ferric beta globulinate has been determined in an effort to elucidate the mechanism of transport of proteins across the capillary wall.

Studies have been made of the mechanism of bone and tooth formation using radiocalcium (Ca 45). The work has demonstrated the key role of the interaction of thyroid in calcium deposition.

A study has been made of phosphorus uptake of the dividing cells. The work indicates an important correlation between cellular activity as evidenced by cell division and radiophosphorus (P 32) uptake.

Cedars of Lebanon Hospital, Los Angeles, Calif.

Radioactive sodium (Na 24) is an excellent vehicle for studying the flow of blood in the body. Radiocardiography has been developed here as a rapid, accurate method of tracing the blood flow through the chambers of the human heart. The tracing reveals graphically the condition of the pumping action of the heart within one minute after injection so that enlargement, failure, or normalcy are easily seen. The diagnosis of particular types of congenital defects in children's hearts is still in the process of development.

Other aspects of the circulation are also being analysed with regard to return of venous blood from the feet to the heart, factors usually causing error in the older forms of circulation time studies, and the rates of absorption into the general circulation of substances injected intramuscularly or just under the skin.

Chemical Corps Technical Command, Army Chemical Center, MD.

Investigators state that di-isopropyl fluorophosphate has been shown to have a specific action on the enzyme cholinesterase. In order to investigate the mode of action of the compound in the body, it has been synthesized on a millimole scale using radiophosphorus (P 32) as part of the molecule.

University of Chicago, Chicago, Ill.

We are using radioactive phosphorus (P 32) as a tracer element to study the metabolism of essential phosphate compounds in the nervous system. In particular we are interested in the problem of nerve fiber degeneration and regeneration and are testing the hypothesis that the nerve cell body (spinal cord) is continually sending out an essential nucleoprotein to the rest of the nerve. Since nucleoproteins contain phosphorus, it should be possible to trace the migration of nucleoproteins by tagging them with P 32. The importance of understanding the nutrition of the nerve fiber, not only for basic physiological but also for medical problems of nerve injury and regeneration, is obvious.

It has previously been found that the addition of ordinary iodine to the diet of rats afforded them resistance against the acute toxic action of the rodenticide (alpha-naphthylthiourea (ANTU)). It was, therefore, of interest to examine the effects of ANTU on the iodine metabolism of the rat. Radioiodine (I 131) studies were made to supplement those previously made with ordinary iodine. It was found that ANTU markedly depressed the uptake of iodine by the thyroid gland which is consistent with the previous findings with other thiourea derivatives. Studies on the rate of uptake of radioactive iodine by the thyroid tissue of normal rats demonstrated that the uptake of iodine is greatly influenced by the quantity of iodine in the diet and is only constant among different animals when they are fed an iodine-deficient diet. Research on iodine metabolism in the normal and ANTU-poisoned animals is being continued and completion of the project is necessary before definite conclusions can be drawn.

Radiophosphorus (P 32) has been used as a tracer to study the transformation of energy released on biological oxidation into a form of energy useful to the cell. Although it has been known for some time that phosphate is involved in this transformation, the details of the mechanism have been obscure because of analytical difficulties. For instance, by using P 32 as a tracer it has been found possible to demonstrate in cell-free extracts of liver that the synthesis of at least part of the molecular structure of nucleic acids is dependent on oxidations for energy.

We are using radiocarbon (C 14) and the stable isotopes C 13 and N 15 in our investigation. It has been found that pyruvic acid amide, in contrast to other amides, is not appreciably hydrolysed in the animal but undergoes "splitting" to acetic acid and an unknown component. The extent of incorporation of isotopic carbon from pyruvic acid into fatty acids, cholesterol, etc., has been determined. This made possible calculation of the role of carbohydrate as precursor for other body constituents. Preliminary results suggest that pyruvic acid together with acetic acid is the main precursor of lipids in the animal body.

Radioactive phosphorus (P 32) is being used to study the metabolism of phosphorus compounds in the body and in microorganisms in order to determine the mechanisms of action of drugs both from the standpoint of their toxicity and their therapeutic action.

Radioactive carbon (C 14) is being used in the biosynthesis of a number of important drugs. The medicinal plants are grown under sealed conditions and radioactive carbon dioxide is introduced into the system thus becoming incorporated in all of the substances of the plant. After a suitable interval the plant is harvested and the drug extracted from it. The medicinal plants being used in this program include digitalis (digitoxin), the opium poppy (morphine, codeine, etc.), tobacco (nicotine), the autumn crocus (colchium) and the atropa belladonna (atropine). In most cases the production of radio-active drugs in this manner will make possible certain investigations which could not otherwise be carried out due to the lack of sufficiently sensitive methods of chemical analysis.

It is also necessary to use the isotope tracer technique to study the metabolic fate of these drugs in the body since the amounts used to produce profound pharmacological effects are very small. The present state of knowledge concerning the metabolism of these important drugs and the mechanism of their action is very incomplete. It is not known, for example, if certain drugs exert their effect as such or whether the effect is a property of one of the metabolic derivatives of the drug which is formed by the action of the body. With reference to the latter case, researches designed to uncover synthetic substitutes are made much more difficult because the chemical nature of the active agent is not known. Possibly the most dramatic example of the value of such studies is the history of the sulfonamide drugs with the recognition that the activities of the original complex molecule resided in a small fraction of the total molecule. Similar phenomena are almost certain to exist with a large number of the more complex drugs currently used in medicine, and investigations designed to uncover these situations are of the utmost importance.

Columbia University, Barnard College, New York, N.Y.

In the first investigation it was found that in mice doses of over 15 to 20 millicuries of radioactivity per kilogram of body weight destroy not only the thyroid gland, but also the parathyroid, and produce extensive loss of the mucus lining of the nearby trachea. Doses in the neighborhood of 5 millicuries per kilogram, though they may destroy most of the

thyroid, permit its survival and eventual regeneration. The parathyroids, however, are irreversibly injured and the tracheal epithelium is lost. One of the suggestions arising from this work is the usefulness of radioactive iodine, properly administered, for non-surgical removal of the thyroid gland. The quantitative data may be of use to physicians in understanding the limits and hazards of clinical use of radioactive iodine.

In the second investigation small amounts of radioactive iodine were given to a number of invertebrates including protozoa hydra, flatworms, annelid worms, clams, snails, lobsters, daphnia and ostracods. By use of the Geiger counter and radioautography it was determined that almost all forms are able to concentrate iodine in some part of the body to a degree almost equal to the thyroid gland of vertebrates.

Columbia University, New York, N.Y.

Our investigation is designed to determine the metabolic fate of representative barbiturates labeled with radiocarbon (C 14). These drugs are extensively employed in medicine as hypnotics, for preanesthetic medication and for psychiatric examination or "narcoanalysis." Thus far the metabolic products of these widely used drugs have resisted isolation and identification by traditional methods. It is our belief that the use of isotopes will make possible the elucidation of the structural changes which the barbiturates undergo in the organism.

An investigator who has been using radioactive ions to study the exchange of ions across nerve membranes states: "The use of radioactive material may become a turning point in the development of research on the mechanism of nerve activity." For half a century, neurophysiologists have assumed that ion movements across the nerve membranes play an essential role in the electrical manifestations observed during nerve activity, but there has been no way of studying such movements. The availability and use of radioactive ions for the study of this problem has changed the situation fundamentally. Significant results have already been obtained. In continuation of these investigations, a project has been worked out which may become of great importance

for the understanding of the basic mechanism of nerve activity and eventually for the pharmacology and the treatment of nerve disorders.

Cornell University Medical College, New York, N.Y.

The amino acid methionine is of unusual strategic importance in the maintenance of health because of its multiple functions in the animal body. It is an essential building block in the structure of living tissues, it supplies the sulfur for the formation of another essential building block, cystine, and it serves as a source of the methyl groups used in the formation of a variety of indispensable compounds. Full understanding of the detailed reactions whereby methionine fulfills its functions, and hence the intelligent understanding and management of diseases that can result from a disturbance of these functions, such as cirrhosis of the liver, can only be achieved through the use of isotopically labelled methionine. The same may be said with respect to the exceptionally potent vitamin, biotin, which is also under investigation in our laboratory.

Methionine containing radiosulfur (S 35) has been synthesized in our laboratory and is being used to study the basic defect in the animal body responsible for the symptoms of the hereditary disease cystinuria. It is also being used to extend our earlier studies on cystine formation conducted with methionine containing both S 34 and C 13.

Methionine containing radiocarbon (C 14) in the methyl group has been synthesized and used to demonstrate that a considerable portion of the essential methyl group is rapidly destroyed in the animal body.

As an adjunct to this problem, it has been shown, through the use of C 14 that the source of carbon used in the formation of urea, the main nitrogenous product of the body is carbon dioxide.

Biotin containing C 14 has been synthesized and is being employed to track down the nature of the essential chemical reactions for which this vitamin is responsible. It is also being used to study the distribution and stability of the vitamin in the body and the rate of its excretion.

Department of the Army, Medical Department Field Research Laboratory, Fort Knox, Ky.

While it is generally believed that thyroid function is increased in cold environments, the evidence on which this view is based is far from clear-cut.

The most recent studies on this subject showed by an indirect method that thyroxine release from the thyroid gland is increased in a cold environment. Radioactive iodine (I 131) was used to estimate the activity of the thyroid gland and the conclusion was reached that exposure of rats to cold (0 degrees – 2 degrees C.) for various periods of time produces a thyroid stimulation which is doubtful after one to three days, definitely after seven days, maximal at 26 days but absent after exposure for 40 days.

These conclusions were based on a study of the uptake of radioactive iodine by the thyroid gland and its conversion to diiodotyrosin and thyroxine.

In most experiments a moderately large amount of carrier iodide was used (5 micrograms) and it was shown that after exposure to cold the uptake of radioactive iodine and/or its conversion to diiodotyrosin and thyroxine was increased at first, but returned to normal after 40 days. With smaller amounts of carrier (0.2 micrograms), however, a decreased uptake of radioactive iodine was obtained during the first seven days of exposure to cold. No longer time intervals were studied and no explanation given for the observation.

The experimental evidence on which these early workers based their conclusions appear far from convincing and thus a reinvestigation of thyroid function after exposure to cold seemed necessary. The supposed absence of thyroid stimulation after exposure to cold for 40 days or longer is a point especially in need of either confirmation or correction.

It is intended to expose rats to a temperature of 0 degrees – 2 degrees C. for periods up to 50 days and to study their thyroid function by measuring the uptake of true tracer doses of radioiodine (no carrier added) and also of large does of iodide.

The first procedure will serve as a true label of the course of endogenous iodine while the second one will measure the thyroid's capacity to take up exogenous iodine.

A third procedure which is contemplated for use as a

measure of thyroid function is the determination of protein bound radioactive iodine of the plasma.

These experiments should furnish good evidence as to whether or not thyroid function is really stimulated by the cold and whether or not this stimulation persists.

Detroit Institute of Cancer Research, Detroit, Mich.

Radiocarbon (C 14) has made possible for the first time a detailed study of the distribution and metabolic alterations of carcinogenic hydrocarbons beyond the point where the characteristic fluorescence of such compounds is lost. By means of these experiments we believe it will be possible to study the changes involved in the production of cancer in experimental animals on a more fundamental basis than has been undertaken.

Distillation Products, Inc., Rochester, N.Y.

Radioactive carbon (C 14) has been used in this laboratory for synthesizing radioactive alphatocopherol (vitamin E). Studies are now under way to determine the distribution, utilization, and metabolism of this compound in the animal body. The use of such a labeled compound enables us to detect smaller amounts than can be detected by chemical means and also enables us to determine the fate of a given dose of this compound despite the large amounts of this vitamin normally present in the non-radioactive form.

Emory University, Emory, Ga.

Radiosodium (Na 24) has been used to investigate the status of the circulation of blood in the extremities. The method used has consisted of injecting radioactive salt solution, sodium chloride, into the muscle and measuring the rate of its disappearance by the circulation. In this manner a diagnosis of the degree of impairment of the circulation can be made. Critical evaluation of drugs and procedures which are generally believed to improve the circulation can be objectively studied.

General Foods Corporation, Hoboken, N.J.

A great many iron compounds have been used in mineral supplements for livestock. In order to obtain more information on the physiological availability of these compounds, several of them, both soluble and insoluble, were prepared from radioactive iron (Fe 55, 59), fed to both white rats and to cattle, and traced through the animal system by means of a Geiger counter. In general, the soluble iron compounds were more readily absorbed by animals than the insoluble compounds, but differences were observed in the availability of the water-insoluble compounds. For example, iron sulfate was more readily absorbed than iron phosphate, which in turn seemed to be a better source of iron than iron oxide. Such studies will serve as a guide in the selection of iron compounds to be incorporated in mineral supplements for livestock feeding.

A study has been made of the comparative physiological availability of water soluble and insoluble zinc compounds. Zinc carbonate and zinc chloride made from radioactive zinc (Zn 65) have been fed to white rats and to cattle. From an examination of the blood, urine and faeces of these animals, it seems that both are suitable sources of dietary zinc. Such findings serve as a guide in the selection of the most suitable zinc compound for mineral supplements.

Although requirements are very low, copper is an essential dietary constituent for livestock. The physiological availability of copper in copper carbonate has been determined by the use of radioactive copper (Cu 64). This water-insoluble compound was shown to be effective in supplying copper which appeared rapidly in the plasma soon after feeding of the compound. By such tracer studies, the value of the specified compound as a mineral supplement for cattle may be determined readily.

When salt blocks for cattle are iodized with soluble iodine compounds, much iodine is lost upon exposure to atmospheric moisture. This difficulty is avoided by using water-insoluble iodine compounds, but it remained to be shown whether such compounds were effective in supplying iodine to the animal system. Radioactive iodine (I 131) was used to synthesize dithymol diiodide which was fed to white rats and to heifers. The iodine in this water-soluble compound was shown to be physiologically available for use by the thyroid.

Georgetown University Medical School, Washington, D.C.

Radioactive calcium (Ca 45) has been used in animals to determine whether the distribution of compounds of calcium which are water-soluble differ in their behaviour and distribution in the body from compounds of calcium which are oil-soluble. The isotope has also been used to determine the utilization of calcium ions by various forms of animal and human tumors.

These studies have shown that the oil-soluble forms of calcium are retained in the body for longer periods of time than the water-soluble form and are more apt to be distributed to the soft parts and bones than the water-soluble forms. They show that several forms of cancer concentrate the calcium ions.

This line of investigation has proved important in the study of the metabolism of calcium in both normal and malignant tissues.

Harvard School of Dental Medicine, Boston, Mass.

Our studies have been designed to test and improve various available methods for determining the quantities and distribution of radioactive phosphorus (P 32) in the enamel and dentin after the radioactive material has been injected intravenously. The best method for separating enamel and dentin in relatively large quantities consists of powdering the crowns of teeth and centrifuging the resultant mixture in bromoform. The heavier enamel particles collect at the bottom while the dentin particles and particles from the dentine-enamel junction float on the surface. Thus the radioactivity of these two samples can be independently determined. Our tests have shown that the radioactivity of the enamel thus prepared is a true value characteristic of the overall activity of the enamel, that no radioactivity is present in the bromoform used, and that no radioactive dentin particles are contaminants of the enamel. The samples of dentin and enamel prepared by this method represent an average value, since all regions of the dentin and of the enamel are represented in the final samples.

More accurate methods for the localization of the radioactivity in each of these tissues have been possible through the use of the radioautograph. Ground sections of teeth or

of sections through the jaws were made by a rapid plastic embedding method; these were applied against selected types of photographic film to allow the radioactivity of the sections to produce images roughly characteristic of the amount and distribution of the active materials.

At best, radioautographs were useful to demonstrate relative distributions of the radioactive materials without presenting accurate determinations of the exact activity of a unit weight of any region in a unit time. To achieve this result it was found possible to remove small samples of enamel and dentin by diamond drills from carefully selected and representative regions of the enamel and dentin at various distances from the surface of the teeth or from the pulp. The activity of the various regions of the teeth prepared in these studies was sufficiently great that samples as small as 2 and 3 milligrams could be collected with satisfactory accuracy.

The results of these three methods have been demonstrated to be sufficiently satisfactory in repeated tests to merit their use in extensive experiments on the metabolism of the hard dental structures. It is obvious from these experiments that the surface enamel and the secondary dentin of erupted teeth have become highly radioactive and that the external dentin and the internal enamel have but slight activity in comparison. At present sufficient experiments have not been performed to merit the interpretation of what the results mean in terms of the relative routes of metabolism in enamel and dentin.

Harvard Medical School, Boston, Mass.

We have been using radiophosphorus (P 32) to study the phosphorus turnover in carcinoma of the human stomach. In connection with this investigation we are developing an intragastric counter. We are carrying on spectrographic studies of gastric tissues and gastric tumors and other types of biological tissue. Methods of determining and measuring small amounts of chromium in tissue are being perfected. We are also carrying on partition studies with P 32 on the blood of cancer patients.

In another program we are studying the metabolism of dihydroxyproline, ornithine, methylene-labeled succinic acid, sorbitol and gluconic acid, the latter two being in the diabetic

rat. As a part of the same program we are studying the fate and turnover of injected uric acid in the normal human, the gouty and hyperuricemic human, the rat and the Dalmatian coach-hound. We are also studying the mechanism which causes obesity in rats subjected to hypothalmic injury.

In still another phase of the work we have been making studies related to the formation of cerebrospinal fluid using radiosodium (Na 24) and other radioactive isotopes. We are also determining the uptake of radioactive phosphorus in normal brain as compared with brain tumor. In another study we are investigating the turnover of radiocalcium (Ca 45) in lobster nerve.

We have been using deuterium as a tracer in the study of carbohydrate and fatty acid metabolism of heart muscle, in intact animals and in heart-lung preparations. The method has involved enrichment of the body water with deuterium oxide, isolation of glycogen and fatty acid from the heart muscle at intervals after such enrichment and determination of the deuterium concentration in the samples isolated. From the rate of incorporation of deuterium into these substances from the body water it is possible to calculate the rate of synthesis of the substance. The influence of certain vitamin and hormonal deficiencies upon these rates of synthesis is under study.

We have been using radiocarbon (C 14) in our investigations. One investigation has been concerned with making a comparison of the rate of oxidation of carboxyl-labelled succinate in the normal and adrenalectomized rat. Another problem pertains to a comparison of the rate of incorporation of radiobicarbonate into the liver slice protein of the normal and adrenalectomized rat. A study is also being made to determine the utilization of C 14-labelled glucose by isolated muscle from hypophysectomized rats.

An investigator who has been using radioactive sodium (Na 24) to study the rate of formation of cerebrospinal fluid in man states that the results thus far are throwing light on the cause of a number of obscure disorders affecting the brain. The patients are those in whom an increased pressure has developed inside the head. This pressure has been caused by an imbalance in the formation and absorption of the cerebrospinal fluid within and outside the brain with accumulation of an excess of fluid.

An investigator has been using radioactive iodine (I 131) to study the rate at which aqueous humor flows out of the eye. It was found that the aqueous humor is secreted into the eye from the blood and that most of it leaves the eye by a simple flow process. This study is important from the standpoint of devising treatment for glaucoma.

It is our purpose to study the kinetics of respiration and circulatory function in normal subjects and in patients with various types of pulmonary or cardiac and circulatory failure. This involves a long preliminary period of study (a) to perfect physical methods of measurement and technique and (b) to establish the normal absorption curve for radioactive argon (A 37) to other gases.

Harvard Medical School—Massachusetts General Hospital, Boston, Mass.

The radioactive potassium (K 42) employed in our investigation has permitted us to measure the total amount of potassium in the body, a measurement not previously obtainable in the living patient. By this method we have been able to determine the amount of potassium lost by disease and the amount needed for replacement to restore the patient's health.

The results of our research indicate that in the presence of cancer, intestinal obstruction, peritonitis, and other depleting diseases, the human body may lose one-eighth to one-fourth of all its potassium. Potassium is the most important alkali substance in body cells, and its replacement is essential to the building of new tissues, the healing of wounds, and the restoration of sick people to health.

Johns Hopkins University, Baltimore, Md.

Radioiodine (I 131) has been synthesized into paraiodoaniline, subsequently diazotized to dysentery toxin and the distribution of the toxin followed after various modes of administration in the rat. This investigation is part of a program aimed to define the effects of bacterial toxin in the mammalian body. It is also part of a program to investigate the specific inter-relations of a natural toxin and

its physiological target in an effort to learn something of the specific mechanism of immunity and of protein synthesis.

These studies have given definite concentration values for dysentery toxin in all organs of the body and have shown that most of the toxin is taken up by the liver.

Radiocarbon (C 14) has been successfully synthesized into the amidine group of arginine and will soon be fed to mice to label preformed serum protein. The mice will then be immunized and it is hoped that the C 14 content of the specific antibodies isolated will throw light on the question of whether or not antibodies are composed of newly synthesized protein or of preformed protein which has undergone a rearrangement.

Massachusetts Institute of Technology, Cambridge, Mass.

It is inconceivable that the research we have undertaken could have been attacked without the use of radioisotope tracers. Even the use of stable isotopes could not have served as only the radioisotopes such as radiocarbon (C 14) are capable of surviving the dilutions necessary in our work.

Aside from developing more reliable methods of assaying carbon radioactivity and of preparing organic compounds containing radioactive carbon, our efforts have been directed towards the study of the differences in the living processes of healthy and cancerous cells. So far, we know that some substances which inhibit growth in normal tissue cause cancer and then cannot inhibit the growth of the tumor. Further, we have observed that a cancerous tissue will incorporate five to seven times as much tagged amino acid as will healthy tissue. This phenomenon may lead to a technique of therapy.

We are using deuterium as a tracer element to study the metabolism of fatty acids. The isotope is incorporated into a fatty acid by replacing some of the hydrogen atoms originally present in the acid. The acid then becomes "tagged" or labelled; its metabolic fate in the body can then be readily followed.

Using this tracer technique, we are endeavoring to learn more about the metabolic pathways taken by four saturated fatty acids after they have been ingested. The deuterium tracer affords us the only way to distinguish between dietary fat and fat originally present in the body. In this way, we

can trace the steps taken by fatty acids during their catabolism as well as identify the tissues where they are deposited.

Phytates are present in many foods, especially cereals, and have been reported to interfere with the absorption of minerals from the gastrointestinal tract.

We are using radiocalcium (Ca 45) to study the effect of phytates on the absorption and metabolism of calcium. In order to determine the amount of calcium absorbed it is necessary to differentiate between the calcium from the test meal and that already present, hence the use of the isotope is of great value. Since phytic acid is a fairly common constituent of the diet, it is of importance to determine to what extent, if any, it interferes with the absorption of calcium and thus interferes with the formation of bones and teeth, in animals and human beings.

In an earlier study we used radioiron (Fe 55 and Fe 59) to study the effects of food phytates upon the absorption of iron. Phytates do interefere with iron absorption, but this interference seemed to be no greater than the interference due to the bulk of the diet. As the solids content of the meal was increased, the iron absorption decreased proportionately. The absorption of radioiron from a breakfast was only one-fifth that observed when the same amount of iron was given with a glass of water. Radioiron is very useful in studying those factors which interfere with, or assist, the normal metabolism of iron.

Massachusetts Memorial Hospital, Boston, Mass.

Radioactive iron (Fe 59) has made possible the " labelling " of red blood cells for studies on the preservation of red blood cells in blood banks.

Radioactive iron is also being used for studies of various serious, and as yet incurable, types of anemia. Information is being obtained which may aid in developing a satisfactory treatment for such anemias.

Radioactive zinc (Zn 65) is being used to study the growth and function of red blood cells and white blood cells in patients with various types of anemia and leukemia. Such studies have already indicated that zinc is of fundamental importance in the function of these cells. Its exact role

is yet to be determined and the radioactive isotope will make possible studies which otherwise could not be performed.

Mayo Clinic, Rochester, Minn.

Phosphoric acid is liberated from organic compounds in the muscles during work. With P 32 we found that this acid is held in the muscle and recombines in its original organic form immediately after working ceases.

Fat absorption from the intestine and the mobilization of fat from body tissues is somewhat related to the metabolism of phospholipids. With P 32 we found that about 5 per cent. of the phospholipid of the liver of rats is newly formed each hour. If part of the liver is injured or removed the remaining liver makes more new phospholipid so that the total production for the body is not diminished. If the body metabolism is increased or decreased by excess or lack of thyroid hormone the phospholipid production by the liver is correspondingly increased or decreased. The amount of fat in the diet does not alter the phospholipid formation of the liver. Certain vitamin deficiencies which produce a very fatty liver do not alter the formation of new phospholipids, although their concentration in the liver is markedly diminished.

Meharry Medical College, Nashville, Tenn.

We are using radioiron (Fe 55, 59) as a tracer in a study of iron absorption in 1,000 hospital admissions. At the present time only very limited data on iron absorption in pathological cases exist. This investigation could be carried out using ordinary iron, feeding it to patients and then examining the excreta for unabsorbed iron. Such a procedure is fraught with difficulty because of the presence of substances in the intestine which interfere with iron determinations, is likely to be time-consuming, and at best is only semi-quantitative. If one attempts to follow a given dose of ordinary iron through blood sampling it would not be possible, since there is no way to distinguish the molecules of ordinary iron compounds from those already present in the blood. If, however, the iron sample administered contains tracer amounts of radioiron the latter can be distinguished from ordinary iron by radio

assay of blood while the chemical and metabolic reactions would not differ materially from those of ordinary iron.

The results obtained so far in this study, which at completion will be the largest survey of this type done up to the present time, in general, confirm the meagre data on humans to be found in the literature and similar experiments carried out with animals. Large uptakes are observed in pregnancies, particularly in the latter stages. No uptakes are observed in cases where the blood picture is essentially normal and where no need for iron absorption exists. This is in line with the newer concept of iron absorption which indicates the presence of a mucosal block in animals plethoric with respect to their iron stores. In infections and inflammatory conditions, little or no iron is absorbed even when the blood picture indicates the need for iron, a finding in line with experiments already reported for dogs. Anomalous results in certain types of heart disease with normal or nearly normal blood pictures have been found in the form of significant iron uptakes. Evidently, the need for iron exists possibly as a compensatory mechanism in such cases. In severe anemias of long standing significant amounts of iron are absorbed, as would be expected from the well-known experiments carried out on anemic dogs.

Memorial Hospital, New York, N.Y.

We are engaged in the synthesis of nucleic acid precursors, purines and pyrimidines, containing stable nitrogen (N 15) and radiocarbon (C 14). These precursors are fed to experimental animals, both normal and with various types of injury, in order to establish the normal and pathological metabolic routes. A new and fundamental observation has been made by this procedure, namely, that adenine alone, of all the materials tested, is deposited in the cell. Moreover it appears to be deposited principally in the cytoplasm. It is hoped by an extension of this study to work out a complete pattern of nucleic acid formation, particularly under conditions involving radiation injury. Other investigators are developing methods for separating the various morphologic constituents of different types in cells, normal and affected by radiation. When these methods have been perfected it is expected that they will be applied to a study of the uptake of nucleic acid precursors marked by radio-active and heavy isotopes.

In another department C 14 has been used for the synthesis of the three steroids, namely, methyl testosterone, progestin and testosterone. We are just beginning biological experiments with these substances. It is hoped to define by their use the amount or hormone localized in target tissue, particularly the genital tissue. It is also expected to obtain more detailed knowledge of the metabolic pathways followed in the synthesis and metabolism of steroid hormones.

Merck and Company, Rahway, N.J.

The isotope tracer method is being applied to benzylpenicillin as a means for its specific determination in the presence of other penicillins, such as penicillin K, F, etc., as well as in the presence of their degradation products and many other substances as occur, for instance, in penicillin fermentation liquors. Such a completely specific assay for benzylpenicillin is not now available and would be of inestimable value in production, research, and control.

We are also using deuterium as a tracer in connection with the fate of the analgesic isoamidine in the animal economy. The results of this use of an isotopic tracer should prove of considerable value in the elucidation of the chemistry of this drug in the living organism and thus should be a contribution to a more detailed medical understanding of its action.

In another assay problem we are concerned with the specific determination of morphine in opium. No reliable assay for morphine in opium appears to have been developed, and since a reliable assay is essential in commercial processing we propose to attempt the development of an isotope tracer method.

National Institute of Health, Bethesda, Md.

We have been using an irradiated unit of antimony for (1) radioautography of parasites and host tissues after injection of host with tarter emetic prepared with radioactive antimony and (2) studies on antimony distribution in mammalian tissue fractions.

Our research programme is considered the first step towards production of labelled antibiotics which may be used to gain

a better understanding of their action. The assay of radioactive sulfur incorporated in the penicillin molecule is superior to the usual chemical assay because of the minute quantities detectable in the former compared to the latter.

Radioactive sulfur (S 35) can be incorporated into the penicillin molecule by growing the penicillin producing mold on a medium containing radioactive sulfur. It has also been found that the radioactive assay for sulfur can be made more accurate than the usual chemical assay.

Radioactive potassium (K 42) has been used to study qualitatively the efficiency of the ventilating system in a building to be used for the study of infectious diseases. This use of the isotope gave the needed information in a much shorter time and was open to less criticism than the standard methods of dust sampling.

New England Deaconess Hospital, Boston, Mass.

Work on radioactive antigens in anaphylaxis is being carried out using bovine albumen and radioactive iodine (I 131). Radiophosphorus (P 32) is being used to determine its uptake from the egg yolk and its effect on the developing chick.

New York University, College of Medicine, New York, N.Y.

We are using isotopes in a study of the effect of adrenal cortical hormones on kidney function and water and salt distribution in the dog. Deuterium oxide (D_2O) is being used for determination of total body water, since it is the only accurate method now available. We plan to use radioactive sodium (Na 24) in a study of the comparison of sodium space and the mechanism of sodium excretion in control animals, in animals treated with adrenal cortical hormones, and in adrenalectomized animals at various levels of substitution therapy.

Our research programme is designed to study the correlation of phospholipid turnover to levels of cholesterol.

A study of phospholipid turnover was undertaken in a very small number of subjects of various ages and on high cholesterol diets. Radioactive phosphorus (P 32) was administered to six subjects, 7 microcuries per kilogram. Blood

samples were drawn at 1, 3, 5, 9, 12, 24, 29, 48, 72, 96, 168 and 216 hours after the initial administration of P 32. The specific activity of the organic phosphorus (phospholipid) was determined in all samples and results were expressed as percentage of original dose administered.

The turnover in six patients did not differ significantly from one another (age range 40 to 82). The feeding of cholesterol did not significantly alter the turnover of phospholipid. Recent publications have not shown significant change in phospholipid turnover in cirrhotic, as opposed to normal, individuals. This fact was confirmed in three patients with cirrhosis of the liver. Our figures for turnover appear to be in the range of those found in the literature. Maximum turnover was found to occur between 48 and 72 hours; the maximal percentages varied from 0.01 to 0.15.

Parke, Davis and Company, Detroit, Mich.

Investigations of a series of drugs having inhibitory effects on the thyroid gland have been greatly facilitated by use of radioiodine (I 131) as a tool for measuring normal and altered thyroid function. As a result of this work carried out on animals, earlier application of certain selected compounds to clinical trial in human patients has been possible. Radiocarbon (C 14) has been used as a means of labelling benadryl, an antihistaminic drug. Radioactive iron (Fe 59) has been employed by investigators to study the effect of radiation on malarial infections in animals.

University of Pennsylvania, Philadelphia, Penn.

In order to learn how the body utilizes food materials for various purposes, it is necessary for us to look inside the body and see where the various molecules go and what chemical changes they are caused to undergo until they are changed into body structure or are excreted. Obviously it is impossible to follow ingested ordinary molecules because they cannot be seen. If, however, such molecules are tagged in some characteristic way and later a tagged compound is found in the body we know that the tagged material introduced must have been changed into the tagged compound which was isolated.

Stated in another way, if we could see a carbon atom we might stain some of them red and then follow them through the organism.

Investigators using radioactive carbon (C 14) to study the metabolism of protein, fats and carbohydrates, state: (1) When lactate (which is related to carbohydrate), containing radioactive carbon is fed to a glycosuric animal, some of the radioactive carbon appears in urinary glucose, some in urinary ketone bodies (which are related to fat metabolism) and some in body fat. This demonstrates that lactate when ingested may be changed into sugar or fat. (2) Radioactive adrenalin is formed when radioactive phenylalanine is administered. This experiment shows that adrenalin may be formed from phenylalanine in the body. It is interesting to note that the structure of phenylalanine is such that one may show theoretically how it can be transformed into adrenalin.

Purdue University School of Pharmacy, Lafayette, Ind.

An enteric coating is the covering that protects a substance from the gastric fluids and releases the contents into the intestinal fluids. This study is directed towards the development of a test which will disclose not only the location but also the time required after administration for the drug to be released into the intestinal fluids.

There is a need for such coatings for several types of drugs:—

1. Drugs that irritate the stomach lining;
2. Drugs that react with the stomach secretions to inactivate the digestive enzymes;
3. Drugs that are inactivated by the stomach secretions;
4. Drugs that should be in high concentration in the intestines to exert their therapeutic activity; and
5. Drugs desired to be delayed somewhat before absorption.

Among the various substances used to coat such drugs are those that are made to be insoluble in the acidic secretions of the stomach and to be soluble in the more alkaline secretions of the intestines. If this were entirely the case, the conditions could be simulated outside the animal body. Actually there is a gradual change from the distinctly acid secretions of the stomach to neutrality and subsequently to alkalinity

because the secretions of the intestinal glands dominate. The problem is to find a substance (or a combination of compounds) that will be sensitive to these slight changes in the medium. Before this type of compound can be intelligently sought, one should have an accurate method of determining solubility as a function of the pH of the medium.

The radioactive material used to develop this test is radiosodium (Na 24), whose radiations have sufficient energy to be detected readily and which has a short half-life. This lessens the danger of permanent contamination. The radioactive material is enclosed in an enteric coat and the pill is given to a rat. The body of the rat is shielded and the tail is continuously measured for radioactivity. Upon release of the material by the rupture of the coat, there is a sudden increase in radioactivity of the tail due to the absorption into the blood of the enclosed compound. The rat is sacrificed and site of the disintegration can be found by examination of the tract.

University of Rochester, Rochester, N.Y.

Radioiodine (I 131) analogues of the preparations employed clinically for cholecystography and intravenous pyelography are being utilized to study the absorption, distribution, and excretion of these widely used contrast media. Preliminary work in dogs indicates that this approach will be particularly instructive as to the behavior of these contrast media at the several blood organ tissue barriers.

Rockefeller Foundation, New York, N.Y.

The radioactive isotope, phosphorus 32, is being used to study the metabolism of the malaria parasite. It has been shown that the avian erythrocyte parasitized with plasmodium gallineaceum takes up labeled phosphorus at a considerably more rapid rate than does the normal cell both in vivo and in vitro. In the course of studies on the factors essential for parasite growth, this isotope is being employed as a means of following the rate of nucleoprotein synthesis by the parasite, both in vivo and in vitro. In addition, by administration of this isotope to normal animals, body fluids and tissue extracts

are being prepared containing a variety of labeled components. Those fluids and extracts known to be effective in maintaining parasite metabolism are being studied with the aim of determining the nature of their active components. If it seems feasible, such studies will be extended to include isotopes of other elements. The above studies are not yet sufficiently advanced to permit any definite conclusions to be drawn.

In addition to the above experiments we have also been using P 32 for tracing the dispersion of inocula introduced by various routes into embryonated eggs. Bland inocula containing approximately 100,000 count per minute of P 32 have been introduced into the allantoic sac, the amniotic sac, the yolk sac and into the blood stream of normal embryos. It has been found that when P 32 is inoculated into the allantoic sac, it tends to remain largely in this location, but when introduced into the amniotic and yolk sacs, it finds its way rather rapidly into the blood stream as well as into the allantoic sac. (Entrance into the allantoic sac may be effected by the necessity of passing through this sac in entering the amniotic sac as well as in entering the yolk sac in older embryos.) P 32 inoculated into the blood stream is detectable after short periods within the allantoic fluid but is not found in the amniotic fluid.

Utilizing these data as a base line, the effect of dispersion of P 32 on influenza virus has been studied. It was found that when the inoculum containing P 32 and influenza virus was introduced into the allantoic sac, it tended to disperse more rapidly than in non-infected eggs.

Experiments are now under way to study the effect of P 32 in more concentrated amounts upon influenza viruses. It is hoped to ascertain if radioactive isotopes tend to enhance mutation of these viruses.

Rockefeller Institute, New York, N.Y.

Mustard gas in low concentration has the unique property of inducing mutations in cells and organisms. Chemical determinations of mustard gas although capable of measuring as little as 5 micrograms are not sensitive enough to detect the amounts involved in the inducing processes. By substituting radiosulfur (S 35) in mustard gas in place of stable sulfur

(S 32), 0.01 microgram of mustard gas can be determined with comparative ease.

St. Louis University School of Medicine, St. Louis, Mo.

Radio-carbon (C 14) is being incorporated into vitamin K in order to follow this vitamin in the animal body and thus gain an insight into the mechanism of blood clot formation and certain deficiency syndromes.

University of Texas Medical School, Galveston, Tex.

With a view to improving methods of resuscitating and of treating the almost drowned, we are investigating what happens during experimental drowning. The water which is "breathed in" during drowning enters the blood in large quantities. By employing isotopic hydrogen (deuterium) in heavy water, we will investigate how much and how rapidly this water enters the blood.

Tulane University, New Orleans, La.

We are using radioactive isotopes to investigate the formation of hemoglobin in subjects depleted of this material by long illness or by trauma. An important aspect of this problem is the accurate measurement of total blood volume and of total circulating red cell volume. It is desirable that some method for measuring blood volume be devised which can be repeated daily if necessary and which can be executed with little advance warning, thereby requiring no previously tagged donor blood. It is also desirable that the method require no injection of foreign substances the physiology or toxicity of which would need to be investigated.

For such a purpose radioactive phosphorus (P 32) works out very well. If a sample of the patient's own blood is properly mixed with radioactive phosphorus, some of the radioactive phosphorus exchanges for normal phosphorus in the patient's blood cells. The dilution of the labeled cells, when reintroduced into the patient's circulation, enables an accurate calculation of the red cell volume.

From this determination of red cell volume and a determination of the concentration of red cells in an aliquot of the whole blood of the patient, the whole blood volume of the patient can likewise be calculated.

In addition to the phosphorus method which measures the red cell volume directly but which depends upon the determination of a hematocrit to give a value for whole blood volume, the use of radioactive iodine (I 131) absorbed to serum protein is being exploited. The method looks directly feasible and if it proves successful, it provides a direct means of measuring the plasma volume. Independent determinations could thus be made of plasma volume directly and of red cell volume directly, and the value for total volume could be obtained by adding the two.

We have been using radiosodium (Na 24) to study some aspects of renal excretion of sodium by normal subjects and by patients with congestive heart failure.

Excretion of radiosodium, following intravenous administration of the isotope, was studied in 12 normal subjects, 10 patients with chronic congestive heart failure, and seven patients with miscellaneous diseases.

The Na 24 required about three times as long to appear in the urine of the patients with congestive heart failure as in the normal subjects. In no instance did the concentration of Na 24 in the urine of patients with congestive heart failure exceed that in the serum; in the normal subjects it varied over a wider range than in the patients with heart failure, and exceeded, equaled or was less than that in the serum. The Na 24 clearance in the patients with congestive heart failure was definitely less than that in the normal subjects.

Washington University, St. Louis, Mo.

The cancer research program of the Barnard Free Skin and Cancer Hospital has been making extensive use of isotopes in a study of epidermal carcinogenesis. Radiocarbon (C 14) has been used in an effort to trace methylcholanthrene in cells during carcinogenesis.

Radiocalcium (Ca 45) has been employed in a comprehensive program of the study of calcium-binding mechanisms in epidermal carcinogenesis and in aging of various mouse tissues. It has been suggested that a growth regulatory

mechanism probably protein in nature and located at the cell surfaces is altered in diverse fashion in both aging and in cancer. Alterations in this protein complex are indicated by changes in calcium binding properties. Much of these data have been procured through the application of the isotope method of tracing and estimating calcium changes.

Study on epidermal carcinogenesis indicates that unlike the normal epidermal cell the squamous cell carcinoma is unable to take up and retain Ca 45. This isotope study is consistent with previous observations that the calcium content of cancer cells is very low and that the ratio of free and bound calcium in cancer cells is radically different from normal.

Age changes in mouse liver as measured by radiocalcium uptake and exchange have been determined. It indicated that the old liver cell contains a high level of calcium, but has a very low exchange rate of calcium ions. This observation is consistent with the fact that there is a higher level of calcium binding in old cells than in the young.

Both of the isotope studies on aging and cancer are being continued largely with the aid of cell fractionation and ultrafiltration with a view towards gaining an understanding of the protein changes at the cell surface. The radioactive isotope of calcium has been of singular value in facilitating these investigations.

In our investigation with radioisotopes we have demonstrated the following:—

Iron injected into the body in small amounts is quantitatively and promptly synthesized into hemoglobin providing the bone marrow is capable of making red blood cells at a normal rate. When, however, the marrow manufacture of red blood cells is decreased, there is a corresponding decrease in the rate at which iron is utilized. These results provide information as to the rate of hemoglobin synthesis in the body, but demonstrate that radioiron (Fe 55, 59) cannot be used in the ordinary manner for measuring iron absorption unless the bone marrow is functioning normally.

Iron absorption with radioiron has ordinarily been measured by determining what percent of a given oral test dose appears in the circulating blood as hemoglobin. Because of the previous considerations the methods for measuring absorption have been augmented to include determination of unabsorbed radioiron eliminated in the feces. With this technique we have shown that iron deficient persons absorb

more iron than do normal subjects. However, patients with various types of anemia may absorb relatively large amounts of iron in spite of adequate iron stores. These results have caused workers to question the currently held theory that the intestinal mucosa, influenced by iron stores in the body, acts as a major regulator of iron metabolism by accepting or rejecting iron according to body needs.

Small but definite amounts of iron are regularly excreted by the intestinal tract. The statements often made to the effect that the mammalian organism has no capacity to excrete iron except by hemorrhage is thus shown to be an over-simplification.

University of Washington, Seattle, Wash.

Two problems are under investigation here which involve the use of radioactive isotopes. The one is concerned with the synthesis of radiocarbon (C 14) labeled stilbestrol and investigation of its behavior in body processes, particularly its possible bi-conversion to natural sex hormones. The other is the synthesis of C 14 labeled xanthopterin which will be used in the investigation of the action and interconversion of pterias, including folic acid and vitamin B.

Beth Israel Hospital, Boston, Mass.

Investigators have been using radioactive iodine (I 131) to study and treat diseases of the thyroid gland and also certain patients with advanced heart disease and angina pectoris. Many patients in whom other forms of treatment have failed have been found to respond satisfactorily to radioactive iodine. The optimum schedules of treatment are being ascertained on the basis of radioactive tracer studies and clinical observations which are now in progress.

Biochemical Research Foundation, Newark, Del.

Radioactive iodine (I 131) has been given orally to a patient with angio-invasive adenoma of the thyroid metastasizing to the bones of the pelvis, the lower spine and one of the

ribs. The iodine has been given in doses of about 30 millicuries every two weeks and the results followed by Geiger counter surveys. Although there seemed to be some concentration of the radioactive iodine by the tumors, X-ray film indicated gradual progress of the tumor. It was finally concluded that the radioactive iodine was accomplishing nothing and its use was therefore abandoned.

Birmingham Veterans' Administration Hospital, Van Nuys, Calif.

Radioactive iodine (I 131) is being used

(1) As an aid in the diagnosis of thyroid diseases;

(2) For the treatment of thyroid cancer in carefully selected cases;

(3) In a basic study of the biochemistry of the thyroid gland (where its use has resulted in the detection of hitherto unsuspected iodine-containing chemical compounds in the thyroid).

Brooklyn Cancer Institute, Brooklyn, N.Y.

Research of carcinoma of the thyroid as well as the study of leukemia, polycythemia and hyperactivity of the thyroid gland and also polycythemia cases treated with radioactive phosphorus (P 32).

University of California Hospital, San Francisco, Calif.

Radioiodine (I 131) has proved to be useful in studying disease of the thyroid, normal action of the thyroid, and the fate of iodine in the body. It has also been useful in treating certain diseases of the thyroid such as toxic goiter.

Cedars of Lebanon Hospital, Los Angeles, Calif.

Radioactive iodine (I 131) is being used to treat and diagnose thyrotoxicosis (goiter, Grave's Disease) and to treat carcinoma of the thyroid. We have been able to treat many

cases which were inoperable or which had not responded to other forms of thyroid therapy, without the surgical risk which usually accompanies this condition. A total of 44 patients adequately treated were cured. However, as far as the details of the treatment are concerned, such as dosage and total time necessary for therapy, the use of radioiodine remains in the research stage.

Cleveland Clinic Foundation, Cleveland, Ohio

Five cases with tumor in the neck were studied with radioiodine tracer doses before operation or bipsy. Radioautographs of removed tumor tissues were made. Nine cases of suspected hyperthyroidism were studied with radioiodine tracer doses and sufficient evidence obtained to make a definite diagnosis.

Columbia University, College of Physicians and Surgeons, New York, N.Y.

Radioactive iodine (I 131) has been used to study thyroid function in about 350 cases, to treat hyperthyroidism in about 65 patients, to prepare radioautographs in 73 cases of known or suspected thyroid cancer, and to treat three suitable cases of thyroid cancer with functioning metastases.

The tracers are valuable as a diagnostic aid in determining whether the patient has a thyroid disorder. This technique is particularly valuable in children, where other methods are not very satisfactory. The treatment of hyperthyroidism has been very successful; about 85 per cent. of the treated patients have responded favorably. The method is of particular value in cases recurrent after surgical treatment.

Radioautographic studies of primary thyroid cancer give information as to the probable uptake in metastases already present or which may occur later. Such studies point the way to possible therapy. Therapy itself is too recent to evaluate.

Cook County Hospital, Chicago, Ill.

We have used radioactive phosphorus (P 32) in the treatment of polycythemia rubra vera and chronic leukemais. The

therapeutic results obtained have been gratifying. Radiophosphorus, given in tracer doses, has been shown to be of definite value in the differential diagnosis and prognosis of peripheral vascular diseases. This radioisotope has also been used in the differential diagnosis of breast tumors.

Jefferson Hospital, Philadelphia, Penna.

Using radioactive phosphorus (P 32) and radioactive iodine (I 131) to study the therapeutic and clinical effect on patients with polycythemia, leukemia, hyperthyroidism and cancer of the thyroid. At the present time radioactive phosphorus is the treatment of choice in patients with primary polycythemia (vera). It is a satisfactory therapeutic agent for chronic leukemia. Radioactive iodine is a very satisfactory therapeutic agent in hyperthyroidism, particularly in those patients who cannot undergo surgical procedures or who are sensitive to anti-thyroid medications. Radioiodine is satisfactory in those cases of thyroid cancer the cells of which concentrate iodine.

Jewish Hospital, Philadelphia, Penn.

We have used radioactive phosphorus (P 32) in treating a case of myeloid metaplasia exhibiting a leukemoid response. Satisfactory improvement of the treated patient has been observed.

We plan to use radioactive iodine (I 131) in an investigation of fungus infection. We plan to experimentally produce sporotrichosis in guinea pigs and to evaluate the response to both radioactive and stable iodine in an effort to demonstrate the mechanism of the response.

Johns Hopkins Hospital, Baltimore, Md.

The major problems of hypothyroidism in childhood being studied with the aid of radioiodine (I 131) are:—

1. Can athyreotic cretinism be diagnosed with certainty at a very early age before clinical signs are definite?
2. Can different degrees of athyreosis be measured?

3. Can congenital absence of the thyroid be distinguished from failure of thyroid function developing later?
4. Can the diagnosis of thyroid deficiency be made when all clinical signs have been obscured by treatment?

Studies are being made of the curves showing radioactive uptake and discharge measured over the neck as compared to curves showing the circulating background measured over various other parts of the body. The urinary excretion of I 131 is also being measured. Studies are being made on children with athyreosis and other types of hypothyroidism, on normal and on hyperthyroid patients. There are striking differences in the various groups. We believe that in the untreated patient we can definitely distinguish between athyreotic patients and normal or hyperthyroid individuals. Also it seems possible to distinguish between completely athyreotic patients and those with partial hypothyroidism. The effects of thyroid therapy, iodine, thyrotrophic hormone, antithyroid drugs and potassium thiocyanate on the rate of uptake and discharge will be studied in the various groups of patients. We believe it will be possible to develop methods of accurate diagnosis and that our studies will extend our knowledge of the physiology of the thyroid.

Massachusetts General Hospital, Boston, Mass.

One phase of the problem concerned with the therapeutic use of radioactive iodine has been the advisability of using it in pregnant women. Because the age at which the fetal thyroid begins to function was not known, we have studied this process by tracer techniques in pregnant women who, for other reasons of health, required an interruption of their pregnancy. Indications are that the human fetal thyroid begins to collect radioiodine after the fourth month of pregnancy. It is therefore assumed that treatment up to this time would probably be a reasonably safe procedure.

Mayo Clinic, Rochester, Minn.

Radioiodine has been found to be rapidly absorbed from the stomach at a constant rate, varying from about 3 to 6

percent per minute. It appears in the blood stream as iodide and then disappears at a regular rate, dependent largely upon the state of the thyroid and renal function. In the normal individual most of a dose of radioiodine is excreted in the urine and most of the remainder is fixed in the thyroid. In individuals with hyperthyroidism proportionately more is fixed in the thyroid. In patients with myxedema little or none is fixed in the thyroid. Apparently in all individuals a small amount, averaging about 10 percent of a dose, cannot be accounted for in either the urine or thyroid. Observation of urine samples discloses that radioiodine is excreted at a relatively constant rate which in normal individuals is about 7 percent per hour. This percent refers to the total quantity present in the blood and its equilibrium fluids.

In individuals with depressed thyroid function the excretion rate is reduced. Comparison of blood and urine samples permit the calculation of iodide clearance giving an accurate measure of renal function. In vivo measurements over the thyroid gland show the rate of iodide fixation by the gland. This data is interpreted as a measure of the rate at which thyroid hormone is being synthesized. In normal individuals this rate is found to be about 4 percent per minute, but in individuals with hyperthyroidism the rate may be increased 10 to 20 fold. Radioiodine may be used to study another function of the thyroid; namely, its ability to concentrate iodide collected from the blood as distinct from its separate ability to synthesize iodide into organic thyroid hormone. Simultaneous observations made on a patient having radioiodine in the blood, the thyroid, the urine, and other parts of the body result in a fairly complete picture of the behavior of this substance. Such studies offer considerable promise for advancing the knowledge of the normal and pathologic physiology of the thyroid in health and disease.

Radioiodine has also been incorporated into a synthetic thyroid hormone. Its administration to a patient suffering from lack of this hormone permits the observation of its behavior in the body.

Meharry Medical College, Nashville, Tenn.

Using radioactive gold (Au 198) in the treatment of tumors in humans. For certain types of inoperable and otherwise

untreatable tumors this isotope shows considerable promise. A considerable amount of fundamental research must, however, be carried out before its widespread application becomes feasible.

University of Minnesota, Minneapolis, Minn.

Radioactive diiodofluorescein has been employed in an effort to diagnose and localize brain tumors before operation. To date this method has been used successfully in a majority of clinical cases. In several instances this technique has proved more accurate than clinical opinion based upon routine neurological examination and the electroencephalogram. Perfection of this technique should increase the accuracy of diagnosing and localizing brain tumors, and thereby reduce the present operative mortality and morbidity of such tumors.

Radioactive sulfur (S 35) in methionine is being used to study the metabolism of various organs. These studies will be extended to include certain types of cancer.

Radiophosphorus used in conjunction with pressure cuffs has been used for determining its effect on circulation in the extremities of certain patients. The information thus obtained has been helpful in establishing an improved method of treatment.

Radioactive iron (Fe 59) has been used for determining uptake by red blood cells in one patient suffering from hemochromatosis and one patient with hyperchromatic anemia. The information obtained has been of value in formulating therapeutic methods.

Santa Barbara Cottage Hospital, Santa Barbara, Calif.

The use of radium for hemangiomata over epiphyses in infants is dangerous because of the gamma-ray effect on bone growth. Surface application of P 32 instead of radium is being used with satisfactory results to date. Plaques have been designed which afford protection to both operator and patient. No affect on bone growth is expected because of the absence of gamma radiation and the relatively slight penetration of the beta radiation.

Sinai Hospital, Baltimore, Md.

Among the many serious problems in the field of medicine one of the most important is thrombosis of the veins and its graver complication, pulmonary embolism. This particular disease kills more people than cancer of the stomach. In order to attain an ideal objective—that is the prevention of thrombosis of the veins—one must have a thorough knowledge of the venous blood flow throughout the body, but more specifically in the lower extremities. In an effort to understand the blood flow in the lower extremities we have used radiosodium (Na 24) as a tracer to determine the segmental linear venous velocity in the legs. Without the use of this radioactive tracer it would have been impossible to measure precisely the rate of blood flow within any one part of the body. Now with the use of radiosodium and a Geiger counter one can measure quite accurately the linear venous velocity, thereby adding to the fundamental knowledge concerning the dreaded disease, venous thrombosis and pulmonary embolism.

CHAPTER XII

RADIOISOTOPES

SPECIFICATIONS AND CHARGES OF THE U.S.A. ATOMIC ENERGY COMMISSION

IN addition to the U.S.A., Great Britain and Canada are now producing radioisotopes for release to independent laboratories. The following official U.S. list gives a reasonably accurate indication of the materials available, or likely to become available from reactions designed for this purpose. The data is therefore of immediate interest to workers in this field.

It will be noted that there are four distinct services:—

1. Pile-irradiations of customers' own materials.
2. Supply of Separated Isotopes.
3. Supply of Fission Products.
4. Supply of Irradiation Units.

Introduction

The U.S. Atomic Energy Commission is now in a position to accept requests for radioisotopes from foreign countries.

Radioisotope production processes have improved sufficiently in the first year of domestic distribution to permit supplying reasonable demands from outside the United States. Especially is this true for those isotopes of particular value in biological and medical investigations.

Radioisotopes are producible in the uranium chain-reacting pile by two processes: (1) the fission of U 235 nuclei and (2) neutron absorption by nonfissionable nuclei. Radiomaterials listed hereunder, with the exception of Iodine 131, are produced by the latter process. "Fission Products," obtained from process (1) above are not in routine production and therefore have not been included here.

Neutron-induced Radioisotopes

Neutron-induced radioisotopes producible in the pile are formed by (1) simple neutron absorption (n, γ) reaction,

yielding a radioactive isotope of the parent element, (2) transmutation (n, p) or (n, α) reactions, yielding radioisotopes which differ chemically from their parents, and (3) (n, γ) reaction followed by a decay chain, yielding radioactive daughters non-isotopic with the target element.

Production of neutron-induced radioisotopes involves the insertion of an element, in a suitable elemental or compounded form, into the pile and its subsequent removal. Materials to be activated are placed in small aluminium containers. The containers are then inserted into holes in a graphite block or "stringer," which composes part of the graphite and uranium structure of the pile. The block, loaded with containers, is pushed into the interior of the pile through an opening in the surrounding thick concrete shield and is irradiated for a period varying from a few days to several months.

Isotopes produced by the above neutron-induced reactions are available in chemically unprocessed irradiated units. Some are also available in a form chemically separated from the target material. Each of these forms is more fully explained below.

Irradiated Units

Unprocessed irradiated materials are shipped in the aluminium cans as they are removed from the pile, except for packing in containers which stop harmful radiation. In this case no chemical separation process on the active material is done prior to shipping. The term "Irradiated Unit" is used to describe such an activation.

When the target element is irradiated as a compound, the other elements in the compound are chosen so as to produce: (1) no radioisotopes, (2) short-lived radioisotopes, or (3) radioisotopes easily separated from those produced by the target element. Oxides of metallic elements, for example, make suitable target compounds since oxygen is not activated. In some cases an irradiated unit of a compound may contain several radioisotopes, which are all useful and easily separable.

Target materials are chemically and spectroscopically analyzed and are chosen for their high purity. Since minor or trace quantities of chemical contaminants will nevertheless

be present, extremely small quantities of radiocontamination will be produced in most units. For the majority of uses the radiocontaminants due to impurities will be insignificant.

Production time required for irradiated units will vary from two weeks to six weeks. Generally a higher priced unit takes a longer time to produce.

Separated Radioisotopes

A transmutation reaction yields a radioisotope which differs chemically from the target material. When a radioisotope of an element is produced by transmutation, it will not be diluted with " carrier " (stable isotopes of that element) other than that which is already present as an impurity in the target material.

A separation of the desired active species is usually made before use.

Several of the radioisotopes, which are very useful in biological and medical application and hence in constant demand, are chemically separated routinely and an effort is made to keep stocks on hand for shipments. Separated Carbon 14, Phosphorus 32, Sulfur 35 and Calcium 45 are available in this group. The specifications for these materials are given later.

The same consideration of chemical separability holds for the daughters of neutron-induced decay chains—Iodine 131 from tellurium bombardment is an example.

No guarantees of radiochemical or chemical purity or other such characteristic may be made, although every effort will be made to produce as high quality material as possible. Analyses will be furnished with each shipment.

Separated radioisotopes are sold by millicuries as defined later.

Carbon 14, because of its long half-life, is kept in stock and deliveries can be made promptly. Other separated materials (I 131, P 32, S 35 and Ca 45) are processed in batches and shipment can usually be made from Oak Ridge each week.

Publications

For the use of its staff and maintenance of reference files, the Isotopes Branch should be supplied with three copies of a report, within six months after completion of research, stating the results of investigations carried on with isotopes obtained through its facilities. The user should publish the results in an appropriate technical or scientific journal or permit the U.S. Atomic Energy Commission to arrange for such publication.

Clinton Laboratories

The pile at Clinton Laboratories, Oak Ridge, is the major producer of radioisotopes for off-Commission distribution. Research and development on production and separation processes at the facility have markedly increased the availability of the useful radioisotopes. Actual sale and distribution of radiomaterial is made by Clinton Laboratories (which acts as the " supplier " under a contract with the U.S. Government). Requests for allocation must first be submitted and approved by the Isotopes Branch of the Commission.

Argonne National Laboratories (Chicago, Illinois) and the University of California Radiation Laboratory (Berkeley, California) have also carried on extensive research in the production of isotopes and in radiochemistry. Credit for initial research in these fields must be shared by many laboratories and individuals, both within the United States and abroad.

Transportation and Customs Clearance

Shipping charges must be paid by the requester. Clinton Laboratories will package materials for shipment and deliver them to the carrier, for consignment to any point within the United States. Payment for all charges, customs clearance and transportation outside continental United States will be the responsibility of the authorized agent of the foreign government.

How to Estimate Costs

1.	Number of units[1] desired		
2.	Price per unit	$	
3.	Total (1 × 2)		$
4.	Handling charges[2] ...		
5.	Cost of material (3 + 4)		$
6.	Deposit on shipping containers[3]		
7.	Total amount of remittance (5 + 6)		$

Shipments are made f.o.b. Clinton Laboratories, Oak Ridge, Tennessee, U.S.A. Transportation costs including return of container will be paid by requester.

[1]Millicuries for processed materials and irradiated units for unprocessed materials. A millicurie is defined for the purpose of this catalog as 3.7×10^7 disintegrations per second. For cases in which there is an indeterminant mixture of isotopes, absolute measurements of activity cannot be given. In such cases the " millicurie " means 3.7×10^7 beta emissions per second in the sample.

[2]A handling charge of $25 is made for each shipment (each item constitutes a shipment). On approved continuing orders for isotopes with half-lives of less than 30 days the handling charge for the first shipment will be $25 and $10 for each subsequent shipment.

[3]A deposit of $125 will be required on returnable containers used to ship gamma-ray emitters. A refund will be made upon return of container, express prepaid, in good condition, within fourteen (14) days from date of receipt of shipment. Such containers must not be used for any other product than that shipped therein. Charges for damaged parts will be made as follows :—

	$
Container	85.00
Shipping crate	20.00
Tools	20.00
Total	$125.00

Separated Radioisotopes

Catalogue[4] Item No.

S-1 CARBON 14 — $50.00 per millicurie[5]

Half-life: 5100 y. Beta radiation: 0.154 Mev. Shipped as $BaCO_3$ in which 0.1 to 4.0% of the carbon atoms are radioactive.

S-2 IODINE 131 — $1.70 per millicurie

Half-life: 8.0d. Beta radiation: 0.6 Mev. Gamma radiation: 0.367 and 0.080 Mev. Carrier free in neutral or weak basic solution containing 0.3 to 2.0 millicuries per milliliter. Chemical analysis is furnished with each shipment. Material will meet the following specifications:—

Concentration	greater than 0.3 mc/ml
pH	7-9
Total solids	less than 1 mg/ml
Te inactive	0.1 mg/ml
Te active	less than 1×10^{-4} mc/ml

S-3 PHOSPHORUS 32 — $1.10 per millicurie

Half-life: 14.3 d. Beta radiation: 1.69 Mev. Phosphate ion probably in the form of Na_2HPO_4 containing 0.5 to 3.0 millicuries per milliliter. Chemical analysis is furnished with each shipment. Material will meet the following specifications:—

Concentration	greater than 0.5 mc/ml
pH	7-9
Total Solids	less than 10 mg/ml
Nonvolatile matter	less than 5 mg/ml

[4]Any reference to materials in this catalogue should include the catalogue item number.

[5]Quantities are measured at 8 a.m. on the day shipped.

Catalogue Item No.		
S-3 (*continued*)	P (inert)	approximately 0.025 mg/mc added[6]
	Cl	less than 5 mg/ml
	Fe, Ni, Al	content such that no precipitate is present at pH 7-9

SULPHUR 35—Available in Two Forms

S-4A Labeled H_2SO_4 (in 0.1 N HCl solution) $2.40 per millicurie

S-4B Labeled Na_2S (in 0.1 N NaOH solution) $6.00 per millicurie

Half-life: 87.1 d. Beta radiation: 0.17 Mev. Chemical analysis is furnished with each shipment. Typical analyses are as follows:—

	S-4A No carrier added	S-4B Carrier added
Concentration	1.53 mc/ml	1.96 mc/ml
Total solids	0.8 mg/ml	0.5 mg/ml
Nonvolatile matter	0.3 mg/ml	0.3 mg/ml
SO_4	0.01 mg/ml	0.5 mg/ml
P 32	10 μc/ml	none
Specific activity	—	10 mc/mg

S-5 CALCIUM 45 $4.00 per microcurie

Half-life: 180 d. Beta radiation: 0.3 Mev. Not yet available from routine production. Small batches of carrier free, high specific activity material will be on hand occasionally. Write for additional information.

[6]Carrier free material is available if desired.

Catalogue Item No.		
V	STRONTIUM 89	Half-life: 55 d. Beta radiation: 1.5 Mev. This isotope is not routinely produced but will be available occasionally. If interested write to the Isotopes Branch for details of specifications, availability and price.

Irradiated Units

An "Irradiated Unit" is a specified quantity of target material that has been sealed in an aluminium can and irradiated in the pile. The unit is removed from the pile and shipped in a special container. The unit is shipped without chemical processing.

All radioisotopes available from the Commission are listed in alphabetical order in the tables on pages 191 to 194. Column 4 gives a cross reference to other units or forms in which the isotope is available. Be sure to check all cross references and request the isotopes in the form best suited for your research problem.

Estimated quantities (column 10) are stated for time of removal from the pile. Irradiated units are offered with the understanding that due to variations in production factors the activities may differ 50 per cent. from the quantities estimated.

In those few cases where the value of the target material is appreciable, units are available in two sizes, the standard size and a 1/10 size at a reduced price. Requests for smaller quantities of other units may be approved, but no reduction in price will be made since production costs remain the same.

Outline of Procedure for Handling Foreign Requests

1. All correspondence with the Commission should be in English. It is believed that this will save time, and will avoid misinterpretation of technical information, particularly

Irradiated Units Available from the U.S.A. Atomic Energy Commission

Catalogue item No.	Radioisotopes in unit: Alphabetical list	Radioisotopes in unit: Others present	Also see unit No.	Half-life	Radiation (Mev): Beta	Radiation (Mev): Gamma	Target material: Compound	Target material: Grams	Estimated quantity (mc)	mc/g element (est.)	Price per unit
3A	Antimony 122	Sb 124	3B	2.8 d 60 d	1.36, 1.94 0.53, 2.25	0.57 1.72	Sb	0.20	50 1	250 5	$ 12.00
3B	Antimony 124	Sb 122	3A	60 d 2.8 d	0.53, 2.25 1.36, 1.94	1.72 0.57	Sb	0.20	4 55	20 275	33.00
3C	Antimony 125	Sn 113 Sn 121 Sn 123 Sn 125 (parent of Sb 125)		2.7 y 100 d 62 h 10 d 9 m	0.8, 0.3 K, e 0.8 2.6 ≃2.2	Present 0.085 None Present ≃0.74	Sn	6.2	1.0 1.0 ? ? ?	C.F.* 0.16 ? ? ?	33.00
4	Argon 37	Ca 45		34 d 180 d	K 0.25	None None	$CaCO_3$	25	0.2 0.8	C.F. 0.1	33.00
5A	Arsenic 76			26.8 h	1.1, 1.7, 2.7	0.57, 1.25	As_2O_3	0.06	25.0	560	12.00
5B	Arsenic 77	Ge 71	5C	40 h {11 d {40 h	0.8 {0.6β+ {1.2β+	None 0.6	GeO_2	1.5	0.70 10	C.F. 10	52.00

* Carrier free.

Irradiated Units Available from the U.S.A. Atomic Energy Commission—continued

Catalogue item No.	Radioisotopes in unit		Also see unit No.	Half-life	Radiation (Mev)		Target material		Estimated quantity (mc)	mc/g element (est.)	Price per unit
	Alphabetical list	Others present			Beta	Gamma	Compound	Grams			
5B contd.		Ge 77 (parent of As 77)		12 h	1.9				0.7	0.7	$
5C	Arsenic 77	1/10 of Unit 5B									13.00
11	Bromine 82			34 h	0.465	0.547, 0.787 1.35	KBr	0.9	70	120	12.00
		K 42		12.4 h	3.58 (75%) 2.07 (25%)	1.51 (25%)			3	10	
13	Calcium 45		4	180 d	0.25	None	Sc_2O_3	0.03	0.001	C.F.	33.00
		Sc 46		85 d	0.36	1.12, 0.90			15	750	
	Carbon 14	Available	in separated form								
17	Chlorine 36			10^6 y	0.66	None	KCl	25	0.005	0.0005	33.00
		K 42		12.4 h	3.58 (75%) 2.07 (25%)	1.51 (25%)			200	15	
		S 35		87.1 d	0.17	None			100	C.F.	
		P 32		14.3 d	1.69	None			0.01	C.F.	
19	Cobalt 60			5.3 y	0.3	1.1, 1.3	Co_3O_4	0.9	20	30	33.00

Irradiated Units Available from the U.S.A. Atomic Energy Commission—continued

Catalogue item No.	Radioisotopes in unit: Alphabetical list	Radioisotopes in unit: Others present	Also see unit No.	Half-life	Radiation (Mev): Beta	Radiation (Mev): Gamma	Target material: Compound	Target material: Grams	Estimated quantity (mc)	mc/g element (est.)	Price per unit
21	Copper 64			12.8 h	0.58 $\beta-$ 0.66 $\beta+$ K	1.2 (weak)	Cu	0.32	100	300	$ 12.00
30A	Gold 198			2.7 d	0.97	0.44	Au	0.016	80	5,000	12.00
30B	Gold 199			3.3 d	1.01	0.45	Pt	0.5	10	C.F.	12.00
		Pt 197		18 h, 3.3 d	0.72	Present			7	14	
		Pt 199 (parent of Au 199)		31 m	1.8						
	Iodine 131	Available	in separated form								
39	Iron 59			44 d	0.26, 0.46	1.1, 1.3	Fe	17	1.0	0.06	33.00
		Fe 55		4 y	K	0.07			0.9	0.05	
47A	Mercury 197		47 B	64 h	K, e−	0.075	HgO	14	95	8	12.00
				25 h	K, e−	0.13, 0.16					
		Hg 203, 205		51.5 d	0.3	0.28			40	3	

Irradiated Units Available from the U.S.A. Atomic Energy Commission—continued

Catalogue item No.	Radioisotopes in unit		Also see unit No.	Half-life	Radiation (Mev)		Target material		Estimated quantity (mc)	mc/g element (est.)	Price per unit
	Alphabetical list	Others present			Beta	Gamma	Compound	Grams			
47B	Mercury 203, 205	Hg 197	47 A	51.5 d 64 h 25 h	0.3 K, e− K, e−	0.28 0.075 0.13, 0.16	HgO	14	135 110	11 9	$ 33.00
	Phosphorus 32	Available in separated form									
59	Potassium 42		11, 17	12.4 h	3.58 (75%) 2.07 (25%)	1.51 (25%)	K_2CO_3	22	130	10	12.00
72A	Silver 110			225 d	0.59	0.66 (44%) 0.90 (47%) 1.40 (9%)	$AgNO_3$	7.1	35	8	33.00
72B	Silver 111	Pd 103		7.5 d 17 d	1.0 K	None None	Pd	1	10 ?	C.F. ?	15.00
73	Sodium 24			14.8 h	1.4	1.4, 2.8	Na_2CO_3	0.3	20	150	12.00
	Strontium 89	Available in separated form									
	Sulfur 35	Available in separated form									
91	Zinc 65			250 d	0.4β+ (1%) K, e− (99%)	1.14	Zn	8	15	1.9	33.00
		Zn 69		13.8 h 59 m	I.T. 1.0	0.439			60	7.5	

information relating to health and safety precautions. Correspondence should be addressed to the Isotopes Branch, United States Atomic Energy Commission, P.O. Box E, Oak Ridge, Tennessee.

2. The radioisotopes for which foreign distribution is being authorized are listed and described in the foregoing pages of this catalogue. Additional copies of the catalogue may be obtained from the Isotopes Branch at Oak Ridge. Subject to limitations on availability of supplies, the radioisotopes listed in the catalogue will be furnished for eligible uses abroad—namely, for scientific research, medical research and therapy, including such uses on animals as may be related to medical research and therapy.

3. Each foreign government interested in having radioisotope shipments made to eligible users in its country is requested to address a note to the Secretary of State, referring to this memorandum, and stating:—

a. The name of a representative (or agent) in the United States who will handle matters connected with radioisotope shipments. (Such representative may be a diplomatic official, a commercial concern, or any other person or corporation selected by the foreign government. The representative should be authorized to maintain liaison with the United States Atomic Energy Commission, and to complete financial and shipping arrangements, such as payments for materials, deposits for shipping containers, arrangements for transportation, etc.)

b. That the representative is authorized to certify on behalf of the government to the accuracy of the information set forth in each request for radioisotopes.

c. That the foreign government understands that there are special health and safety hazards arising out of the possession, handling or use of radioisotopes, and that such hazards require special protective measures.

d. That the foreign government agrees that neither the United States Government nor any United States distributing agent shall be responsible for injury or damage caused by, or in the application of, any radioisotopes delivered.

4. Following the deposit of such a note with the Department of State, individual requests for radioisotopes should be submitted to the United States Atomic Energy Commission by or through the representatives designated by the foreign

FORM 313	REQUEST FOR RADIOISOTOPE AEC Form 313 (Jan. 20, 47)	LEAVE BLANK
NOTE →	*Form must be typed with carbon impression on reverse side in order that photo reproduction of extra copies may be made as necessary.*	← NOTE
SEND ORIGINAL COPY ONLY	To: U.S. Atomic Energy Commission, Isotopes Branch, Research Division, P.O. Box "E," Oak Ridge, Tennessee	1. DATE

2. FROM: *(Name of Institution)*	3. LOCATION
4. NAME OF INDIVIDUAL MAKING APPLICATION	5. TITLE AND DEPARTMENT

6. IF MATERIAL IS TO BE USED SECONDARILY IN OTHER DEPARTMENTS OR IN CO-OPERATION WITH OTHER INSTITUTIONS, GIVE DETAILS:

SPECIFICATIONS

NOTE: *Use a separate Form 313 for each isotope. Request only in form and quantities given in Price List unless arrangements for other forms have been made through correspondence.*

7. PRICE LIST ITEM NUMBER	8. ELEMENT AND ISOTOPE	9. QUANTITY DESIRED *(Specify millicuries or irradiation units.)*	10. TO BE DELIVERED AT THE RATE OF *(Specify quantity per week, month, etc.)*

11. ESPECIALLY UNDESIRABLE CHEMICAL CONTAMINANTS	12. ESPECIALLY UNDESIRABLE RADIOACTIVE CONTAMINANTS

13. CHEMICAL AND PHYSICAL FORM

(a) FIRST CHOICE	(b) ACCEPTABLE FORM	(c) FORM IN WHICH TO BE FINALLY USED

14. OTHER DESIRABLE SPECIFICATIONS *(not given in availability list)*

EXPERIMENTAL DETAILS

15. STATEMENT OF INTENDED USES, INCLUDING SYNTHESES TO BE PERFORMED, IMPORTANCE OF INVESTIGATION, ETC. *(A more extensive description may be attached.)*

16. SAMPLE WILL BE MEASURED AS *(ash, gas, liquid, etc.)*	17. GEOMETRY OF SAMPLE *(thin flat, surrounds counter, etc.)*

THIS IS PAGE 1 OF 2 PAGES

Fig. 4—Form of request for Radioisotopes

FORM 313	REQUEST FOR RADIOISOTOPE	PAGE 2 OF 2 PAGES

18. DETECTION INSTRUMENTS TO BE USED (*Specify kinds of instruments and types of circuits.*)

19. NAME AND EXPERIENCE OF PERSON WHO WILL SUPERVISE MEASUREMENTS

EXPERIMENTAL DETAILS FOR "IN VIVO" USES

20. ORGANISMS TO BE STUDIED (*kind*)	21. APPROXIMATE NUMBER
22. ACTIVITY TO BE USED PER ORGANISM	23. NATURE OF SAMPLES TO BE TAKEN FOR MEASUREMENT

HEALTH PROTECTION AND SAFETY

24. DESCRIBE MONITORING PROPOSED FOR HEALTH PROTECTION (*personnel and qualifications, instruments, etc.*)

25. DESCRIBE PROPOSED DISPOSAL METHOD FOR SURPLUS OR WASTE

PUBLICATION

26. PUBLICATIONS ON THIS OR RELATED PROBLEMS BY THE INTENDED USERS ARE FOUND IN (*Name only a few recent papers. In the event applicant has no published articles use space for names of persons familiar with researches.*)

JOURNAL	PAGES	DATE

27. RESULTS OF INVESTIGATIONS USING REQUESTED MATERIAL WILL BE PUBLISHED. MANUSCRIPT WILL PROBABLY BE SUBMITTED TO THE FOLLOWING PUBLICATION:

SHIPPING

Shipments are made F.O.B. Clinton Laboratories, Oak Ridge. The requester will pay all charges. Special shipping arrangements will be made with Clinton Laboratories after this request has been approved by the Isotopes Branch

SIGNATURES

It is recognized by the applicant that this request may be referred to an Advisory Committee or to sub-committees nominated by the National Academy of Sciences and that he has no objection to the disclosure of items contained herein to such qualified review. Three copies of published articles resulting from the use of the requested material will be furnished the Isotopes Branch, Research Division.

SIGNATURE OF APPLICANT

If special approval is required by your institution or firm, person authorized to approve this request should sign here:

TITLE

198

Fig. 4 (contd.)—Form of request for Radioisotopes

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government pursuant to paragraph 3 above. (A new note need not be presented to the Department of State unless the authorized representative shall have changed, or unless there should be some material change in the information supplied in the original registration.) The request may be on a form such as the one printed on pages 196 to 199, or by letter, and should be addressed to the Isotopes Branch, United States Atomic Energy Commission, P.O. Box E, Oak Ridge, Tennessee. The request may be accompanied by a purchase order made out to the Commission's designated contractor (e.g., the Clinton Laboratories, Oak Ridge, Tennessee). It is not essential, however, that a purchase order be submitted until the Commission has issued a "notice of allocation" (see paragraph 8 below). The request should include adequate information on the following matters:—

a. Name and item number of radioisotopes desired (as listed in the catalogue).

b. Quantity desired. (Radioisotopes with half-lives of less than 30 days may be allocated, on one request, in amounts sufficient for six months needs. Shipments may be made at intervals of not less than one week as arranged with the supplier.)

c. Desired time and rate of deliveries.

d. Names and experience of persons who will use materials furnished.

e. Name of institution at which materials will be used.

f. Purposes for which materials will be used.

g. Health and safety measures to be employed.

5. The request also should contain the following undertakings:—

a. That, (1) at intervals of six months after delivery of each shipment of radioisotopes to the representative of a foreign government for forwarding to an investigator in the country he represents, three copies of a progress report on the results of the investigation will be furnished to the United States Atomic Energy Commission, and (2) the results of such investigation if publishable by nature either will be published by the author in an appropriate technical or scientific publication or permission to arrange for publishing such results will be granted to the Commission.

b. That the materials will not be used in a manner other than as disclosed in the request.

c. That qualified scientists irrespective of nationality

will be permitted to visit the institutions where the materials will be used and to obtain information freely with respect to the purposes, methods and results of such use, in accordance with well-established scientific tradition.

6. Requests which the United States Atomic Energy Commission may receive directly from institutions or doctors in foreign countries ordinarily will be referred to the representative designated pursuant to paragragh 3 above, for handling and consideration in accordance with established procedures.

7. Particularly in view of the limited supply of radioisotopes and the special health and safety hazards connected therewith, it is hoped that each interested foreign government will establish adequate procedures for reviewing the merits of a request prior to its submission to the United States Atomic Energy Commission. In this connection, it may be helpful to explain the procedure which is followed in the United States.

In its program of domestic distribution of radioisotopes, the Commission has established criteria for determining which requests should be granted. In all cases, the domestic applicant is required to provide sufficient information on the matters listed in paragraph 4 above, to permit review and evaluation of the merits of the request. Such review and evaluation is made by the " Advisory Committee on Isotope Distribution Policy," a committee chosen from a group of technically qualified scientists nominated by the National Academy of Sciences. This committee and its two subcommittees have been highly effective not only in eliminating impractical or unwise applications of radioisotopes, but also in aiding research investigators to correct and revise meritorious plans and techniques so that more accurate results will be obtained. The adoption of comparable procedures in other countries would go far toward assuring (1) maintenance of adequate health and safety standards, and (2) most beneficial utilizations of the limited supplies of radioisotopes available in the United States for foreign distribution.

8. The foreign request will be reviewed and evaluated by the " Advisory Committee on Isotope Distribution Policy " as in the case of a domestic request. When the Commission determines that the material can be furnished, the Commission will issue a notice of allocation, and will authorize its

designated contractor (e.g., the Clinton Laboratories, Oak Ridge, Tennessee) to make distribution.

9. Shipping instructions should be included with the purchase order. Radioistopes are sold f.o.b. Oak Ridge, Tennessee. Customs clearance and transportation outside the continental limits of the United States should be arranged by the representative designated pursuant to paragraph 3. Shipments will be consigned collect to the representative via rail or air express, to any point within the continental limits of the United States.

10. Payment will be due and payable on receipt of an invoice from the Commission's designated contractor (e.g., the Clinton Laboratories, Oak Ridge, Tennessee).

INFORMATION FOR USERS OF RADIO-ACTIVE ISOTOPES PREPARED EXPERIMENTALLY IN G.L.E.E.P. AT HARWELL

Neutron Flux Available

The maximum thermal neutron flux available for isotope production, when the pile is running at full power, is about 2.5×10^{10} neutrons/sq. cm./sec. The pile is at present (August, 1948), run continuously at the week-end at high power for 60 hours. During the rest of the week it is run intermittently at lower powers. It can be run at powers as low as 1 watt for periods of hours for those who require low fluxes.

It is expected that after the beginning of 1949 Isotopes can be prepared in the bigger pile (B.E.P.O.) at Harwell, in which the neutron flux is expected to be roughly 20 times that in G.L.E.E.P.

Standard irradiations are made in the core of the pile, where the flux is partly thermal and partly of fast neutrons. The thermal column does, however, provide nearly pure thermal neutrons, with some gamma-background.

Specific Activities Obtainable

These can be calculated from the fluxes given above, in conjunction with the values of excitation cross-sections given

by Seren Friedlander and Turkel (Phys. Rev. 72-10-p. 888). At the present early stage it is quite impossible to give any sort of guarantee of the specific activity of material produced in Gleep, especially as the neutron flux varies by a factor of 3 according to the position of the specimen in the pile.

Standard Irradiation Cans

There are two types of standard container at present in use:—

(i) an aluminium can of about 30 c.c. capacity, 3 ins. long by 0.9 ins. i.d., which is hermetically sealed at Harwell.

(ii) a smaller can with a screw top of about 5 c.c. capacity.

Larger containers are available on special request.

Provision of Materials for Irradiation

As a rule common chemicals of " Analar " quality are provided by Harwell. Valuable substances may be charged for at commercial prices. The user will be expected to supply any unusual material.

(a) Samples must in general be of such a size that they fit one of the standard cans.

(b) Solids are preferred to liquids. Volatile or inflammable substances are only accepted in special circumstances and in any case should be sealed into boron-free glass or, preferably, silica containers. Glass or silica may disintegrate under long bombardment even in the low fluxes present in Gleep. The material should not develop a dangerous pressure when heated to 50° C.

(c) Poisonous samples, liable to endanger persons canning or handling them, should be clearly marked, and details given as to the nature of the hazard.

(d) Neutron absorption of the specimen should not ordinarily exceed a value such that $\Sigma N\sigma_a$ exceeds 10 square centimetres. Where N is the number of atoms of any element in the specimen σ_a is the absorption cross-section. (Only very strongly absorbing materials such as *Cobalt* or *Lithium* are liable to exceed this limit.)

(e) Total activity of the sample. For safe handling it is preferable that no activity of the specimen should exceed 100 millicuries on removal from the pile, but this is not a rigid requirement. Transport difficulties may occur if the activity of the sample exceeds a few millicuries.

Time Table of Irradiations

Until further notice loading and unloading will be carried out only once in the week as follows:—

General load—Thursday afternoon.

General unload—Monday morning.

The "isotope week" therefore lasts from Thursday to Monday.

As a rule materials will be irradiated for one of the following periods of time, and the loading dates will be as indicated:—

1 week—the Thursday of each week.

2 weeks—alternate weeks (i.e., September 16 and 30, October 14, etc.).

4 weeks—At intervals of four weeks (i.e., on September 16, October 14, November 11, December 9, etc., etc.).

12 weeks—At intervals of 12 weeks (i.e., on September 16, December 9, etc., etc.).

CHAPTER XIII

RESEARCH FRONTIERS

A Discussion of the Nature of Current Problems

IT is a remarkable fact that in spite of the astonishing facility with which man can now control the behaviour of an electron, his *fundamental* knowledge of it has advanced very little in the last half century. Fortunately, it is not necessary to know what an electron *is* in order to make it work for us.

One can almost exhaust precise knowledge of an electron by saying that we know its mass and charge, and can determine whether this is positive or negative. We also know that it has a spin which gives it a definite angular momentum of constant value. This implies that it has an " axis " or the equivalent of an axis. The laws of quantum mechanics demand a stability of angular momentum about the " axis," and this in turn implies the possibility of a natural frequency of angular oscillation about the " axis."

We also know the " size " of an electron, or more correctly, the order of magnitude of its virtual radius, that is about the same as a proton or neutron which is roughly 1×10^{-13} cms, whilst nuclear radii are somewhat larger, the maximum, for a heavy element, being of the order 10×10^{-13} cms.

Again we know that an electron has certain wave properties, and indeed is associated with a " wave-length " which varies inversely with its momentum, giving the phenomenon of electron diffraction.

Finally, we know that we can " manufacture " electrons or rather an electron-positron pair by materializing a gamma ray of not less than 1.02 mev energy, that is, sufficient to give the correct mass by Einstein's Law.

The foregoing " specification " of an electron may seem reasonable enough but it leaves a number of fundamental questions unanswered. For example there is a hidden relation between the mass (m), charge (e), rest-energy (mc^2) and effective radius (r_0).

If we regard the mass of the electron as representing the rest-energy equivalent of the electrostatic energy $\propto \frac{e^2}{r_0}$

we can determine τ_0 from the expression: $\tau_0 = \alpha \frac{e^2}{mc^2}$ where α is a constant, approximately unity—and the numerical evaluation of this is very close indeed to the figure mentioned above: 1×10^{-13} cms.

This at first seems quite reasonable, but leads to a radius for a proton nearly 2,000 times smaller than for an electron, whereas we know that it is very nearly the same size. For a neutron it gives no answer at all, because e is then zero. Worse still, when we regard a neutron as a proton which has shed a positron, we have to account for the fact that the neutron mass is slightly *greater* than the proton mass.

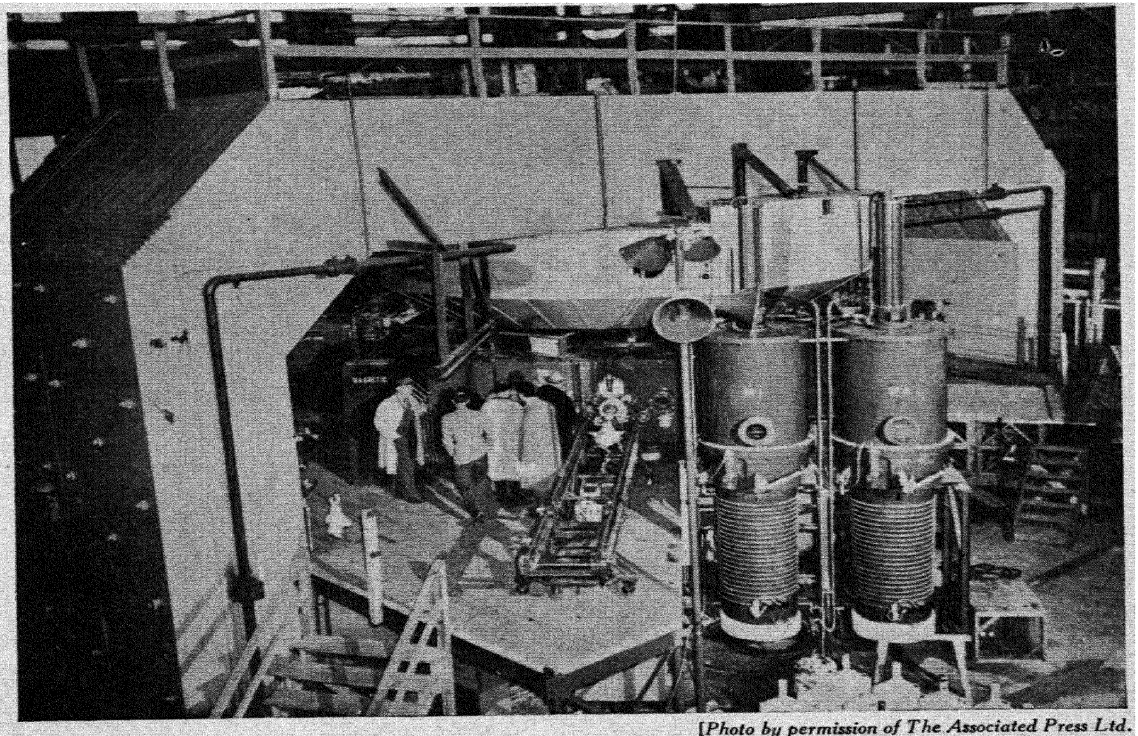
This at first suggests that the apparent agreement between the approximate radius of an electron and the " electrostatic " radius, is accidental, except, of course, that $\frac{e^2}{mc^2}$ is necessarily correct in a dimensional sense. If we were to regard the proton as a more fundamental particle than an electron—which we are perfectly entitled to do—there would, of course, be no such impressive agreement.

It may well be, therefore, that the electron mass is in fact accounted for mainly by its " electrostatic " self-energy, which in turn is correlated with the force exerted between an electron and a positron; whilst the proton and neutron masses are accounted for mainly by a self-energy of a *different* type, correlated with the very powerful but short range forces which are known to exist between proton-proton, proton-neutron and neutron-neutron. These three couplings are all of about the same order of magnitude, and in so far as they are independent of charge and do not obey an inverse square law, are fundamentally different from " Coulomb " forces. The law governing these short-range forces has not yet been established, but it would be very satisfactory if it can account for the proton and neutron mass, in the same way as the Coulomb law accounts for the electron and positron mass.

If so, one would expect the " short-range " law to be such that the " short-range " self-energy of a particle is actually *increased* on shedding its charge, and vice versa, which would enable the anomalous changes in mass to be accounted for in the proton-neutron transition—

$$P \longrightarrow N, e^+, n.$$

(where P = proton, N = neutron, and n = neutrino.)



[*Photo by permission of The Associated Press Ltd.*

The 4,000-ton magnet of the new Cyclotron at Berkeley, California, with a maximum potential of 200 million electron volts.

In the neutron-proton transition, however, we are compelled, for reasons of conservation of charge, to assume that the process results in the creation of an electron-positron pair, permitting the emission of an electron, and the retention of the positive charge by the neutron, which then becomes a proton, with loss of rest-energy due to the interference in the self-field, giving:

$$N \longrightarrow P, e^-, n.$$

The foregoing discussion is not offered as a solution of the problem but rather by way of illustrating that the problem exists. Indeed, to account for the differences in the masses of electron, proton and neutron is one of the most fundamental duties of modern physics. When this has been done, we shall no doubt be able to account simultaneously for the meson mass and the neutrino mass, the latter being a theoretically essential particle of zero charge and almost zero mass.

It appears also to be essential that the neutrino spin should be $\frac{1}{2}$ so that there may be conservation of momentum, in addition to the conservation of charge already provided for. The conservation of momentum suggests not merely the reality of a neutrino, but also suggests that the neutrino has a spin equal and *opposite* to that of the electron or positron emitted.

In addition, the neutrino theory accounts for the energy distribution in the beta ray spectrum, but there is still a difficulty about the neutrino mass. It must be exceedingly small compared with an electron, but cannot be zero or it would have no angular momentum.

At the lower end of the beta ray spectrum, the neutrino has a velocity approaching the speed of light and its " mass " is then almost entirely accounted for by the Einstein increment. As it has no charge it has an estimated range of several thousand *miles* in lead, so the scientist has little chance of stopping it to see how it behaves, or even if it actually exists!

The physical difference between a positive charge and a negative charge, which, presumably, would determine the physical difference between a positron and an electron, is difficult to interpret. It is, of course, not to be confused with the " positive " and " negative " terms used in electrostatics, which merely refer to the value of an electronic (negative) charge, in relation to a datum level. All the evidence indicates that the positron and electron are identical in *all* respects except the " sign " of the charge, the real significance

of which is a secret, not yet to be expounded to the lay mind.

In 1935 the Japanese scientist, Yukawa, proposed a theory for nuclear fields, based on the hypothetical existence of a singly charged particle of about 200 electron-masses. Such particles, mesons, have actually been observed in cosmic radiation, and at first it appeared that this was a brilliant confirmation of Yukawa's predictions. More recently, however, mesons of about 320 m have also been observed, whilst unconfirmed experiments indicate the possibility of mesons ranging from 30 m to nearly 1,000 m. Using the great cyclotron at the Berkeley Laboratory, California, Lattes, a former colleague of Powell at Bristol, has observed the materialisation of mesons of about 320 m in copious numbers. It is clear that these giant research tools will soon throw a great deal of light on mesons and meson fields of force, and the quantum mechanics of the field may well correlate with the variation in mass.

The intensive search for precise data on fundamental particles serves to remind us once more how limited is our knowledge in other directions. For example, we know that an electron can absorb and emit electro-magnetic radiation. What happens to an electron in these circumstances is a mathematical paradise, and it is not considered altogether reasonable to ask for a physical picture of a vibrating electron. Here again, however, we know the experimental results with some precision. The electron emits electro-magnetic radiation which has a constant speed in vacuo of 3×10^{10} cm. per sec., that is, the speed of light (c). This electronic emission has, theoretically no limits, upper or lower, to its wave length and frequency. It is referred to, for convenience, by different names such as radio, infra red, visible light, ultra violet, X-ray and gamma ray. Some idea of the range of wave length may be had from the fact that the ultra short (centimetric) waves used in radar are about one million million times longer than the gamma ray used to generate a pair of electrons in a betatron.

The remarkable thing is that an electron with dimensions of the order 10^{-13} cm., can emit radiation with such relatively enormous wave lengths. It is even more remarkable that the energy in the radiation is emitted in packets or quanta, and not in a smooth continuity. This phenomenon was discovered by Planck in 1900, and even to-day it is difficult to give a simple explanation of the *meaning* of Planck's Law.

Now Planck's Law, $E = h\nu$, which is the foundation of modern physics, states simply that the energy in each quantum of electro-magnetic radiation is given by the frequency per second multiplied by 6.6×10^{-27}. This gives the exact energy in ergs—for example if the frequency is 10^{27} per second, each quantum has an energy of 6.6 ergs. It will be seen that the energy is inversely proportional to the wave length, but this practically exhausts our knowledge of a "quantum." There *are* no answers to questions as to its "geometry" or extension in space, and yet it has a most definite physical reality. For example when a gamma quantum strikes a free electron, both it and the electron fly off at precise geometrical angles, just as though the quantum were an actual particle. One cannot help feeling that there is some quite simple, direct and fundamental explanation of the meaning of Planck's Law, which may emerge with the deeper insight which the next few years may bring.

In nuclear physics, it is found convenient to express probability of a particular event by a "cross section." Statistically, the centers of the atoms in a thin foil can be considered as points evenly distributed over a plane. The center of an atomic projectile striking this plane has geometrically a definite probability of passing within a certain distance (r) of one of these points. In fact, if there are *n* atomic centers in an area A of the plane, this probability is $n\pi r^2/A$, which is simply the ratio of the aggregate area of circles of radius r drawn around the points, to the whole area. If we think of the atoms as impenetrable steel discs and the impinging particle as a bullet of negligible diameter, this ratio is the probability that the bullet will strike a steel disc, that is, that the atomic projectile will be stopped by the foil. If it is the fraction of impinging atoms getting *through* the foil which is measured, the result can still be expressed in terms of the equivalent stopping cross-section of the atoms. This concept can be extended to any interaction between the impinging particle and the atoms in the target. For example, the probability that an alpha particle striking a beryllium target will produce a neutron can be expressed as the equivalent cross section of beryllium for this type of reaction.

It is conventional to consider that the impinging particles have negligible diameter. The technical definition of cross section for any nuclear process is therefore given by:—

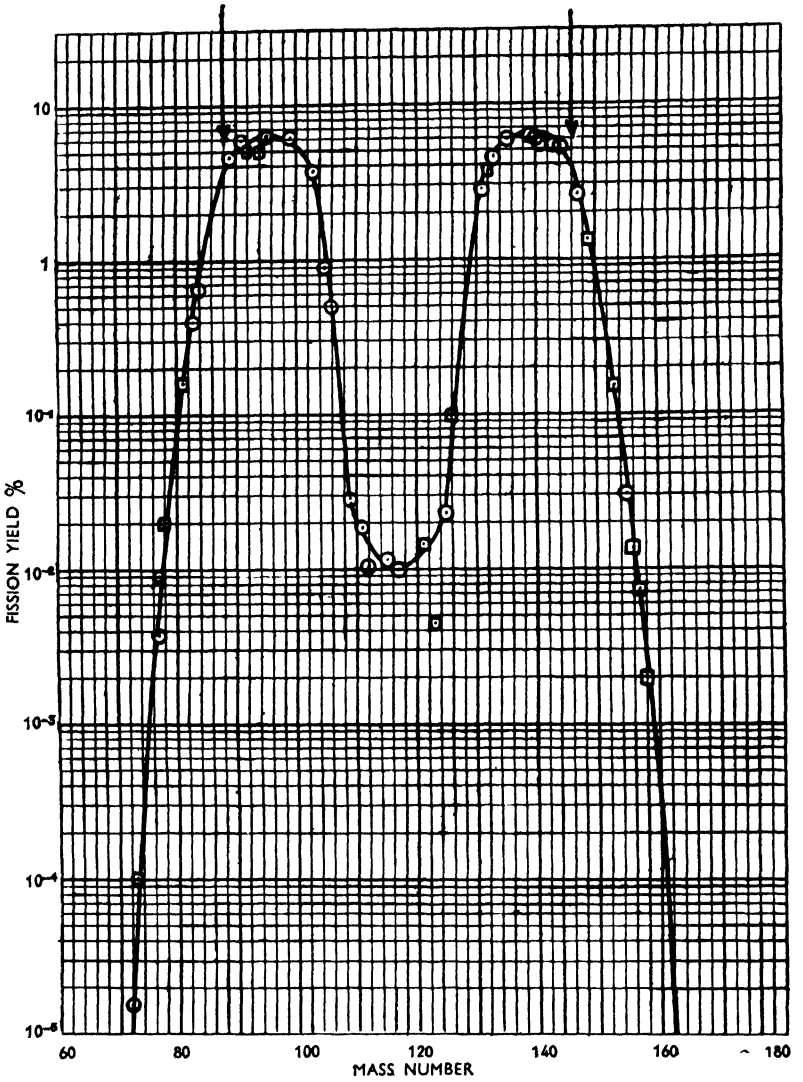


Fig. 5.—FISSION FRAGMENTS OF URANIUM 235.

The vertical scale is logarithmic.

The arrows indicate $\frac{3}{8}$ and $\frac{5}{8}$ fragments which are about 1,000 times more frequent than symmetrical fission.

$$\frac{\text{number of processes occurring}}{\text{number of incident particles}} = \left(\begin{matrix}\text{number of target}\\ \text{nuclei per sq. cm.}\end{matrix}\right) \times \left(\begin{matrix}\text{nuclear cross-}\\ \text{section in sq. cm.}\end{matrix}\right)$$

Cross sections can be computed for any sort of process, such as capture, scattering, production of neutrons, etc. In many cases, the number of particles emitted or scattered in nuclear process is not measured directly; one merely measures the attenuation produced in a parallel beam of incident particles by the interposition of a known thickness of a particular material. The cross section obtained in this way is called the total cross section.

A nuclear diameter is of the order of 10^{-12} cm. We might therefore expect the cross sections for nuclear reactions to be of the order of $\pi d^2/4$ or roughly 10^{-24}cm^2 and this is the unit, one Barn, in which they are usually expressed. Actually the observed cross sections vary enormously. Thus for slow neutrons absorbed by the (n, γ) reaction the cross section in some cases is as much as $1{,}000 \times 10^{-24}$cm.^{2}, while the cross sections for transmutations by gamma-ray absorption are in the neighbourhood of $(1/1{,}000) \times 10^{-24}$ cm^2.

In recent experimental work on the properties of the nucleus, Amaldi has actually measured the radius of the nucleus for a large number of elements.

For example, the radius of a beryllium nucleus is 3.22×10^{-13} cm. and for lead 9.00×10^{-13} cm.

The nuclear radius can be represented as a function of the atomic weight A by the expression

$$R = b + r_0 A^{1/3}$$
$$\text{with } b = 1.5 - 2.0 \times 10^{-13}\text{cm.}$$
$$\text{and } r_0 = 1.3 - 1.0 \times 10^{-13}\text{cm.}$$

A more precise determination of these two constants cannot be made at present, mainly because there are appreciable differences in the values of the nuclear radii of elements of about the same atomic number.

In a controlled nuclear reaction we have three main variables, namely the bombarding particle, the target nucleus, and the ejected particle. In addition, the reaction may depend —and frequently does—on the *energy* of the bombarding particle, as in slow neutron fission. Space does not permit

of the vast field of nuclear reaction to be discussed in any detail, and the interested reader is advised to consult the bibliography. A great deal of tabular data on the reactions of different elements is given in Mattauch (1946), and in Neucleonics (March, 1948), whilst the Sergré diagram is the main source of information on cross sections.

The latest data on nuclear spin is given in the table on page 227, which shows how remarkably promiscuous the values are, ranging from zero to 9/2, which appears to be the maximum. Many attempts have been made to account for and predict this strange assortment of half-integral values —so far without any consistent success.

Perhaps the most striking and unexpected feature in nuclear fission is the sharp division of the nucleus into two unequal masses, very roughly in the ratio 3/8 to 5/8. This is shown very clearly in Figure 5 on page 211. The vertical scale is a logarithmic one, and it will be seen that the probability of a 3/8, 5/8 fission is about 1,000 times that of a symmetrical fission. This diagram gives the percentages of fission products for U.235, and the curves for U.233 and Pu.239 are believed to be similar.

Practically all the fission products are radioactive when formed and decay spontaneously to a stable isotope, usually by beta and gamma emissions. Most of the phenomena have been elucidated, except perhaps the reason for the delayed neutrons—or spontaneous neutrons—emitted by some of the nuclei formed on fission, and which enable a chain reaction to be controlled so conveniently. Another convenient but imperfectly understood phenomena is *spontaneous* fission—that is the nucleus undergoes fission without external agency and releases, in the process, one or more neutrons, which provide a natural source of neutrons for starting up a chain reaction.

Bohr and Wheeler have developed a " liquid-drop " theory of the nucleus, which has had some striking success in predicting fission phenomena, and in this work it is usual to assume that the nucleon density is about the same for all nuclei, giving a " volume " distribution, but H. A. Wilson has recently shown that a model in which all the protons and neutrons are on a shell, one nucleon thick, gives more helpful results in calculating resonance levels. It is probable that the actual distribution of nucleons inside the nucleus is intermediate between a " volume " and a " shell " effect. The

difference between these extremes is that in the former case the radius would vary as $A^{1/3}$ and in the latter as $A^{1/2}$.

For work in the front line of research, an atomic energy pile operating on the principle of nuclear fission has obvious limitations. In high energy physics, special accelerating machines are required which will step up the energy of charged particles towards the limits of the *total* energy of the heaviest nucleus, that is, for element No. 96, about 200 billion electron volts. The range to be covered is a very wide one and is broadly indicated below:—

	Kev.
Electron: rest energy	½
Pair Production: gamma	1
Mass Defect: nuclear fission	10
Meson: total energy	100
Proton or Neutron: rest energy	1,000
Heavy nucleus: total energy	200,000

The absolute limit of energy is when the particle has reached the speed of light—a speed which, according to the law of relativity, cannot be reached by a particle of finite rest mass without its virtual mass becoming infinite.

Charged particles such as electrons, protons, deuterons and alphas can be accelerated in stages by applying small increments of energy by electro-static or electro-magnetic devices such as Van de Graaff generators, linear accelerators, Cockcroft-Walton generators, cyclotrons, betatrons and synchrotons.

Plans were completed in 1948 by the technical staff at the Berkeley Radiation Laboratory for two accelerators many times more powerful than any machine previously built or contemplated. The larger of these new machines will be installed at Berkeley and will have the following main features:—

Type:	Proton-synchroton.
Radius:	55 ft.
Proton energy:	7,000 Kev.
Completion Time:	5 years
Weight of Magnet:	10,000 tons
Estimated cost:	9 million dollars

The second machine to be installed at the Brookhaven Laboratory will be slightly smaller, with a 30-ft. radius. Apart from these future giants, there are already more than

50 particle accelerators in the United States in the million volt range and almost an equal number are under construction or in the blue print stage.

The great majority of them are intended to operate, day in day out, bombarding various target substances to get information and to produce materials obtainable in no other way. The information that they produce—about the nuclear characteristics of materials, for instance, on the behaviour of nuclei under bombardment, or the fission and transmutation of elements—is basic to the future development of atomic energy. Discoveries are also inevitable which will help us to understand fundamental scientific concepts.

The present equations of quantum electro-dynamics are based on the point-charge model of the electron, which leads to divergent difficulties when dealing with dimensions less than the radius of the classical electron referred to above. Also, these equations give the result that for an electron with an *initial* acceleration, the acceleration continually increases and the velocity of the electron rapidly approaches the velocity of light, with emission of radiation, all the time. Thus the equations allow motions that are not observed in practice.

As Dirac has said, as recently as 1946: " It may be that one should get away from the idea of a point-charge electron model. However, the more obvious models of an extended electron may increase the difficulties rather than diminish them."

In the same year, Born writes: " I expect the real solution of our difficulties from the discovery of new facts in the domain of high energy which will be experimentally explored in the near future. Experimental physics is sound and progressing while theory is in a morbid state. If a term in a formula shows a tendency of becoming too large, it is in great danger of being killed altogether, just like politicians in a totalitarian regime."

CHAPTER XIV

INTERNATIONAL CONTROL OF ATOMIC ENERGY

IN 1946, the General Assembly of the United Nations Organization set up a special division—the United Nations Atomic Energy Commission—with general terms of reference to prepare a scheme for the international control of atomic energy.

On May 17, 1948, after two years' work and 222 meetings, the Commission passed a resolution recommending its own suspension *sine die*. The resolution was carried by nine votes to two, the Soviet Union and the Ukraine dissenting.

The problem is now transferred to the entire 58-nations General Assembly which will also have to decide whether and when the Atomic Energy Commission will resume its duties.

Although for the present, the Commission has failed in its primary objective, it has carried out an invaluable programme of exploratory work, particularly on the scientific, technological and administrative problems of international control. This work has served to clarify the position, which may briefly be summarized as follows:—

1. Control is technically feasible; operationally difficult.
2. Control, to be *fully* effective must begin with the production of raw materials and be maintained with increasing vigour as they are processed to nuclear fuels.
3. Control of the refining plants, separators, primary reactors and chemical plants would require a staff comparable in size and skill with the plant staff engaged on actual production of the same materials.
4. Control by an international inspectorate of large plants operated by any nation or group of nations *intent* on diversion of fission materials is very difficult.
5. Control which does *not* partially interfere with national "sovereignty" could not be regarded as effective control.

The technical difficulties of control reside very largely in the relatively small amount of fissible material required to make

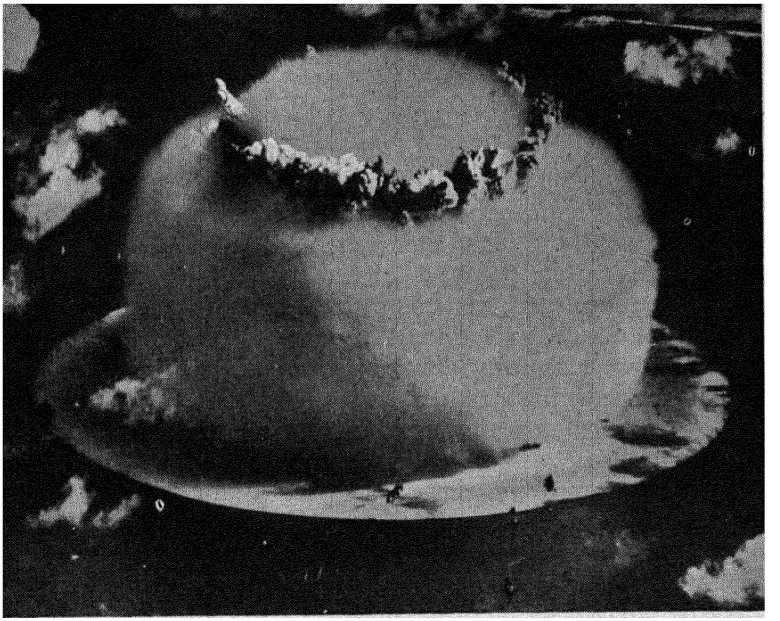


Photo by permission of The Associated Press Ltd.

1. Atom Bomb exploded under water at Bikini on July 25, 1946. The small objects at the base of the eruption are warships.

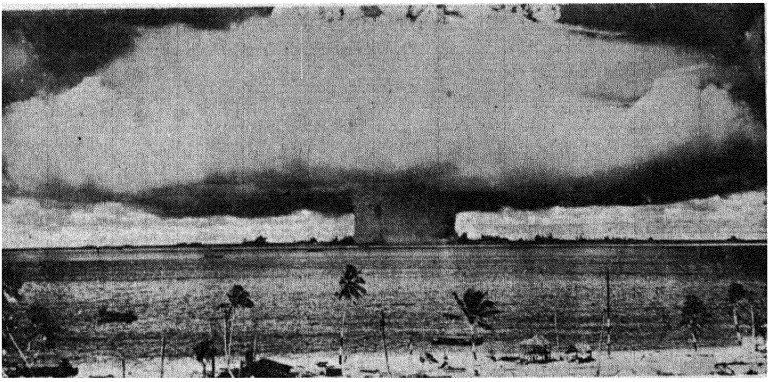


Photo by permission of The Associated Press Ltd.

2. The same as (1) a few seconds later. The power of the bomb can be assessed by estimating the weight of water in the column and the height to which it has been lifted.

an extremely large explosion, and in the relatively vast and complex operations required to produce the deadly finished product.

Whilst international discussions are proceeding on the highest levels, one can but hope that this and kindred problems will find a simultaneous and permanent solution. Against the background of these discussions, however, it may be appropriate to make some brief comment on the more advanced uses of atomic energy as a weapon of war.

The early atom bomb is already known to be a somewhat elementary and inefficient method of using the available energy. It has been estimated that only about one-tenth of the explosive was fully effective in the early bombs. This leaves the possibility of making a given bomb about *nine* times as powerful without increasing its size or contents.

These considerations serve to underline the grim consequences of failure to secure adequate international control, and indeed to emphasise the view that efforts to *agree* on this must *never* be abandoned by civilised nations, however arduous the task or unwelcome the sacrifice.

At the Paris Meeting of the General Assembly, which ended in December, 1948, no agreement was reached on the question of atomic energy, the main issue being whether the destruction or surrender of atomic weapons should take place before, after or simultaneously with the signing of an agreement for the control of atomic energy by the Great Powers. The discussions will presumably be resumed at the next meetings of the General Assembly, commencing on April 1, 1949, in New York.

United Nations Commission on Atomic Energy

This Commission which functions under the Security Council was established at the first meeting of the General Assembly on January 24, 1946.

The Security Council consists of eleven members, each of which has one representative and one vote. There are five permanent members (China, France, U.S.S.R., U.K., U.S.A.), and six non-permanent members elected for a two-year term by a two-thirds majority of the General Assembly.

The Security Council bears the primary responsibility for the maintenance of peace and security.

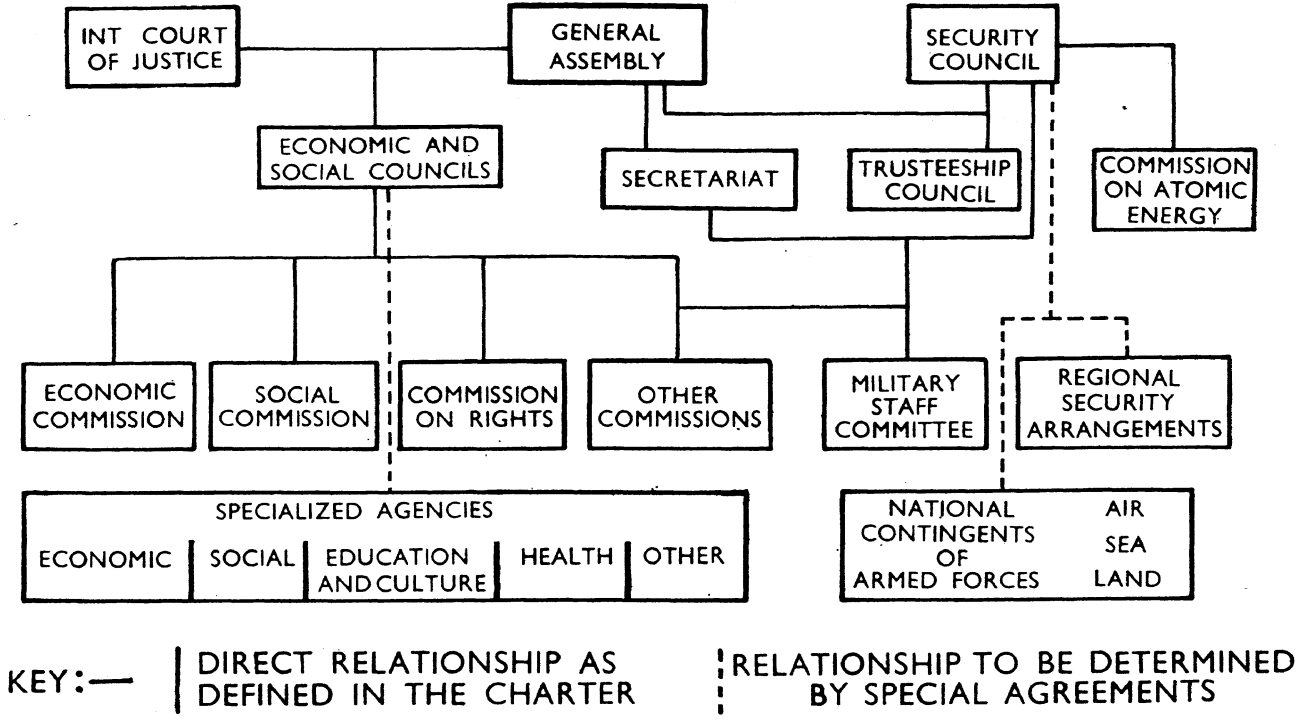


Fig. 6.—Structure of the United Nations
(Permanent Site : Lake Success, Nassau County, N.Y., U.S.A.)

The purpose of the Atomic Energy Commission is the exchange of basic scientific information between nations, the control of the use of atomic energy for peaceful ends, the elimination of atomic and other weapons adaptable to mass destruction, and the prevention of violations and evasions.

It is composed of representatives of the Members of the Security Council and of Canada, if this country is not a member of the Security Council.

H. V. Evatt	Australia
Capt. Alvaro Alberto	Brazil
Gen. A. G. L. McNaughton ...	Canada
Dr. Alfonzo Lopez	Colombia
Dr. Quo Tai-Chi	China
Hafez Afifi Pacha	Egypt
Alexandre Parodi	France
Manuel Sandoval Vallarta ...	Mexico
Dr. van Kleffens	Netherlands
Dr. Oscar Lange	Poland
Faris el-Khouri	Syria
Sir Alexander Cadogan	U.K.
A. A. Gromyko	U.S.S.R.
W. R. Austin	U.S.A.

APPENDIX A

TABLES OF ELEMENTS, ISOTOPES AND NUCLEAR SPIN

Table of Stable Isotopes

THE elements have been divided, for tabulation purposes, into four groups :—

1. Even Z—Even A.
2. Even Z—Odd A.
3. Odd Z—Odd A.
4. Odd Z—Even A.

GROUP 1. EVEN Z—EVEN A

Element	Chemical symbol	Atomic number Z	Mass number A
Helium	He	2	4
Beryllium	Be	4	8
Carbon	C	6	12
Oxygen	O	8	16
			18
Neon	Ne	10	20
			22
Magnesium	Mg	12	24
			26
Silicon	Si	14	28
			30
Sulphur	S	16	32
			34
			36
Argon	A	18	36
			38
			40
Calcium	Ca	20	40
			42
			44
			46
			48
Titanium	Ti	22	46
			48
			50
Chromium	Cr	24	50
			52
			54
Iron	Fe	26	54
			56
			58
Nickel	Ni	28	58
			60
			62
			64
Zinc	Zn	30	64
			66
			68
			70
Germanium	Ge	32	70

GROUP 1. EVEN Z—EVEN A (*Continued*)

Element	Chemical symbol	Atomic number Z	Mass number A
Germanium (*continued*)	Ge	32	72 74 76
Selenium	Se	34	74 76 78 80 82
Krypton	Kr	36	78 80 82 84 86
Strontium	Sr	38	84 86 88
Zirconium	Zr	40	90 92 94 96
Molybdenum	Mo	42	92 94 96 98 100
Ruthenium	Ru	44	96 98 100 102 104
Palladium	Pd	46	102 104 106 108 110
Cadmium	Cd	48	106 108 110 112 114 116
Tin	Sn	50	112 114 116 118 120 122 124
Tellurium	Te	52	120 122 124

GROUP 1. EVEN Z—EVEN A (*Continued*)

Element	Chemical symbol	Atomic number Z	Mass number A
Tellurium (*continued*) ..	Te	52	126 128 130
Xenon	Xe	54	124 126 128 130 132 134 136
Barium	Ba	56	130 132 134 136 138
Cerium	Ce	58	136 138 140 142
Neodymium	Nd	60	142 144 146 148 150
Samarium	Sm	62	144 148 150 152 154
Gadolinium	Gd	64	152 154 156 158 160
Dysprosium	Dy	66	158 160 162 164
Erbium	Er	68	162 164 166 168 170
Ytterbium	Yb	70	168 170 172 174 176
Hafnium	Hf	72	174 176 178

GROUP 1. EVEN Z—EVEN A (*Continued*)

Element	Chemical symbol	Atomic number Z	Mass number A
Hafnium (*continued*) ..	Hf	72	180
Tungsten..	W	74	180
			182
			184
			186
Osmium	Os	76	184
			186
			188
			190
			192
Platinum..	Pt	78	192
			194
			196
			198
Mercury	Hg	80	196
			198
			200
			202
			204
Lead	Pb	82	204
			206
			208

GROUP 2. EVEN Z—ODD A

Element	Chemical symbol	Atomic number Z	Mass number A
Beryllium	Be	4	9
Carbon	C	6	13
Oxygen	O	8	17
Neon	Ne	10	21
Magnesium	Mg	12	25
Silicon	Si	14	29
Sulphur	S	16	33
Calcium	Ca	20	43
Titanium..	Ti	22	47
			49
Chromium	Cr	24	53
Iron	Fe	26	57
Nickel	Ni	28	61
Zinc	Zn	30	67
Germanium	Ge	32	73
Selenium..	Se	34	77
Krypton	Kr	36	83
Strontium	Sr	38	87
Zirconium	Zr	40	91

GROUP 2. EVEN Z—ODD A (*Continued*)

Element	Chemical symbol	Atomic number Z	Mass number A
Molybdenum	Mo	42	95
			97
Ruthenium	Ru	44	99
			101
Palladium	Pd	46	105
Cadmium	Cd	48	111
			113
Tin	Sn	50	115
			117
			119
Tellurium	Te	52	123
			125
Xenon	Xe	54	129
			131
Barium	Ba	56	135
			137
Cerium	Ce	58	—
Neodymium	Nd	60	143
			145
Samarium	Sm	62	147
			149
Gadolinium	Gd	64	155
			157
Dysprosium	Dy	66	161
			163
Erbium	Er	68	167
Ytterbium	Yt	70	171
			173
Hafnium	Hf	72	177
			179
Tungsten	W	74	183
Osmium	Os	76	187
			189
Platinum	Pt	78	195
Mercury	Mg	80	199
			201
Lead	Pb	82	207

GROUP 3. ODD Z—ODD A

Element	Chemical symbol	Atomic number Z	Mass number A
Hydrogen	H	1	1
Lithium	Li	3	7
Boron	B	5	11

GROUP 3. ODD Z—ODD A (*Continued*)

Element	Chemical symbol	Atomic number Z	Mass number A
Nitrogen	N	7	15
Fluorine	F	9	19
Sodium	Na	11	23
Aluminium	Al	13	27
Phosphorus	P	15	31
Chlorine	Cl	17	35
			37
Potassium	K	19	39
			41
Scandium	Sc	21	45
Vanadium	V	23	51
Manganese	Mn	25	55
Cobalt	Co	27	59
Copper	Cu	29	63
			65
Gadolinium	Ga	31	69
			71
Arsenic	As	33	75
Bromine	Br	35	79
			81
Rubidium	Rb	37	85
			87
Yttrium	Y	39	89
Columbium	Cb	41	93
Technecium	Tc	43	—
Rhodium	Rh	45	103
Silver	Ag	47	107
			109
Indium	In	49	113
			115
Antimony	Sb	51	121
			123
Iodine	I	53	127
Cesium	Cs	55	133
Lanthanum	La	57	139
Praseodymium	Pr	59	141
		61	
Europium	Eu	63	151
			153
Terbium	Tb	65	159
Holmium	Ho	67	165
Thulium	Tm	69	169
Lutecium	Lu	71	175
Tantalum	Ta	73	181
Rhenium	Re	75	185
			187
Iridium	Ir	77	191
			193
Gold	Au	79	197
Tellurium	Tl	81	203
			205
Bismuth	Bi	83	209

Group 4. Odd Z—Even A

Element	Chemical symbol	Atomic number Z	Mass number A
Hydrogen	H	1	2
Lithium	Li	3	6
Boron	B	5	10
Litrogen	N	7	14

Table of Nuclear Spin

Atomic number	Mass number	* Spin	Atomic number	Mass number	* Spin
1	1	1/2	49	113	9/2
1	2	1	49	115	9/2
2	4	0	50	115	1/2
3	6	1	50	117	1/2
3	7	3/2	50	119	1/2
4	9	5/2	51	121	5/2
5	10	1	51	123	7/2
5	11	3/2	53	127	5/2
6	13	1/2	54	129	1/2
7	14	1	54	131	3/2
7	15	1/2	55	133	7/2
9	19	1/2	56	135	3/2
11	23	3/2	56	137	3/2
13	27	5/2	57	139	7/2
15	31	1/2	59	141	5/2
17	35	3/2	63	151	5/2
17	37	3/2	63	153	5/2
19	39	3/2	65	159	3/2
19	41	3/2	67	165	7/2
23	51	7/2	69	169	1/2
25	55	5/2	70	171	1/2
29	63	3/2	70	173	5/2
29	65	3/2	71	175	7/2
31	69	3/2	72	177	3/2
31	71	3/2	72	179	3/2
33	75	3/2	73	181	7/2
34	77	1/2	74	183	1/2
35	79	3/2	75	185	5/2
35	81	3/2	75	187	5/2
37	85	5/2	76	189	1/2
37	87	3/2	77	191	1/2
39	89	1/2	77	193	3/2
41	93	9/2	78	195	1/2
42	95	1/2	79	197	3/2
42	97	1/2	80	199	1/2
47	107	1/2	80	201	3/2
47	109	1/2	81	203	1/2
48	111	1/2	81	205	1/2
48	113	1/2	82	207	1/2
			83	209	9/2

* The spin values are those generally accepted in 1948.

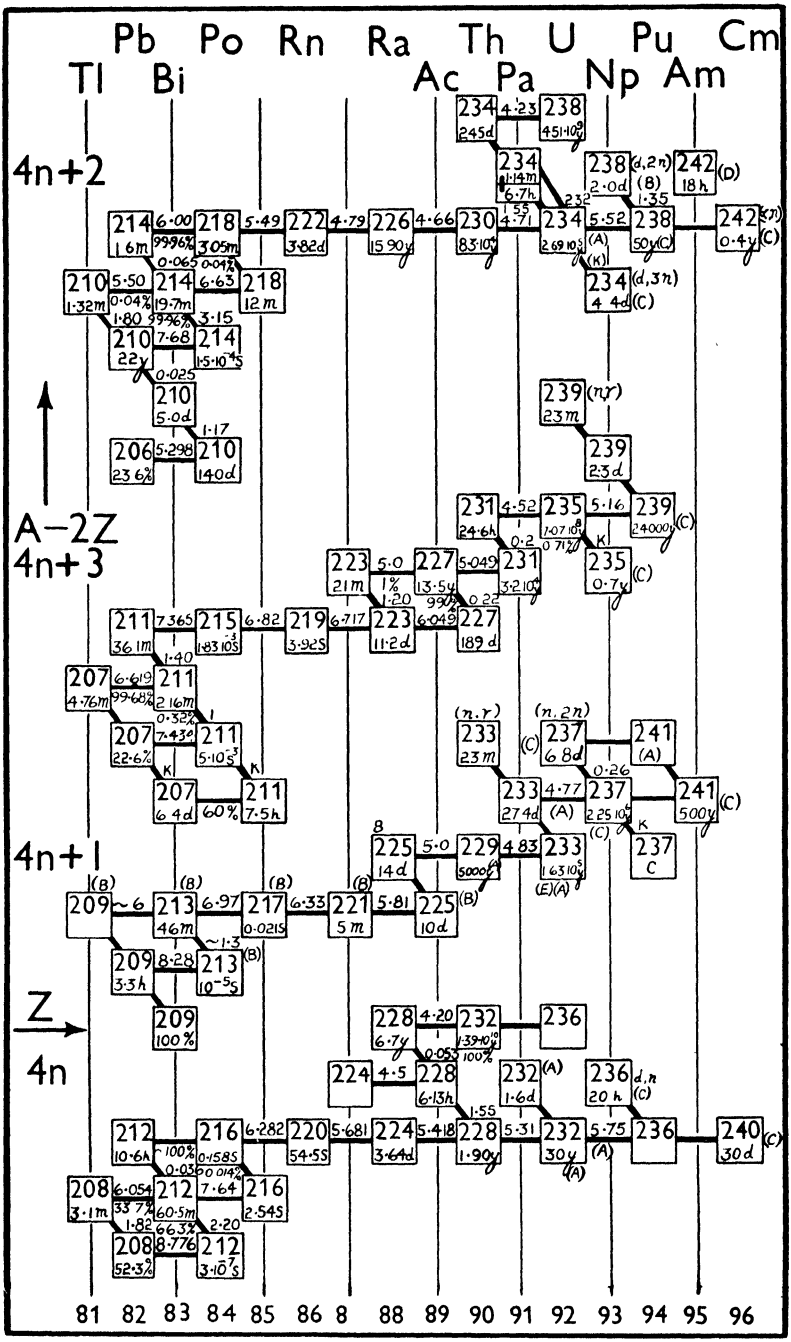


Fig. 7.—The Four Natural Raio-active Series.

APPENDIX B

NATIONAL SCIENTIFIC ACADEMIES

ALGERIA.—Académie d'Algers, l'Université d'Algers, Faculté des Sciences, Algers.
ARGENTINA.—Academia Nacional de Ciencias, Buenos Aires, Argentina.
AUSTRALIA.—The Royal Society of New South Wales, Sydney.
AUSTRIA.—Akademie der Wissenschaften, Vienna.
BELGIUM.—Académie Royale des Sciences, des Lettres et Beaux-Arts de Belgique, Brussels.
BRAZIL.—Academia Braziliera de Sciencias, Rio de Janeiro.
BULGARIA.—Bâlgaraka Akademija na Naukite, Sofia.
CANADA.—Royal Society of Canada, Ottawa.
CHILE.—Academia Chilena de Ciencias Naturales, Santos.
CHINA.—Academia Sinica, Nanking.
COLOMBIA.—Sociedad Colombiana de Ciencias Naturales, Bogota.
CUBA.—Academia di Ciencias, Habana.
CZECHOSLOVAKIA.—Kral. Ceská Spolecnost Nauk Prague.
DENMARK.—Det Kongelige Danske Videnskabernes Selskab, Copenhagen.
EIRE.—Royal Irish Academy, Dublin.
ECUADOR.—Academia Ecuatoriana, Quito.
EGYPT.—Fouad I National Research Council, c/o The Council of Ministers, Cairo.
ENGLAND.—The Royal Society, Burlington House, London, W.1.
FINLAND.—Societas Scientiarum Fennica, Helsingfors; *also* Academie Scientiarum Fennica, Helsingfors.
FRANCE.—Académie des Sciences de l'Institut de France, Paris.
GERMANY.—Akademie der Wissenschaften, Berlin.
GREECE.—Academy of Athens, Athens.
HOLLAND.—Koninklijke Akademie van Wetenschappen, Amsterdam.
HUNGARY.—Magyar Tudomanyos Akademie (Ungar. Akademie der Wissenschaften), Budapest.

INDIA.—National Institute of Sciences of India, Calcutta.
ICELAND.—Hio Islenzka Natturefraeoisfelag, Reykjavik.
ITALY.—Reale Accademia Nazionale dei Lincei, Rome.
JAPAN.—Imperial Academy of Japan, Tokyo.
MEXICO.—Academia Nacional de Ciencias "Antonio Alzate," Mexico.
NEW ZEALAND.—Royal Society of New Zealand, Wellington.
NORWAY.—Det Norske Videnskapsakademi i Oslo, Oslo.
PALESTINE.—Hebrew University of Jerusalem, Jerusalem.
PARAGUAY.—Sociedad Cientifica del Paraguay, Asuncion.
PERU.—Academia Peruana, Lima.
PORTUGAL.—Academia das Sciências de Lisbôa, Lisbon.
RUMANIA.—Academia Româna, Bucarest.
SCOTLAND.—Royal Society of Edinburgh, Edinburgh.
SPAIN.—Academia Espanola, Madrid.
SWEDEN.—Kungliga Svenska Vetenskaps-Academien Stockholm.
SWITZERLAND.—Institut National Genevois, Geneva.
TURKEY.—Türkiyat Enstitüsü, Istanbul.
UNION OF SOUTH AFRICA.—Royal Society of South Africa, Cape Town.
URUGUAY.—Academia Uruguaya, Montevideo.
U.S.A.—National Academy of Sciences, Washington.
U.S.S.R.—Académie des Sciences, Moscow.
VATICAN CITY.—Pontificia Accademia della Scienze i Nuovi Lincei, Citta del Vaticano.
VENEZUELA.—Academia de Ciencias Fisicas, Matematicas and Naturales, Caracas.
YUGOSLAVIA.—Srpska Kraljevska Akademija, Belgrade.

APPENDIX C

BIBLIOGRAPHY

Some Important Books and References

AKERS, SIR WALLACE — "Metallurgical Problems in Generation of Useful Power from Atomic Energy." (1947.) Nature, Vol. 160, p. 182.

AMERICAN CHEMICAL SOCIETY — "Nuclei Formed in Fission: Decay Characteristics, Fission Yields and Chain Relationships." Nov., 1946.

ANDRADE, E. N. da C. — "The Atom and its Energy." G. Bell and Sons Ltd., London.

BETHE, H. A. — "Elementary Nuclear Theory." John Wiley and Sons, Inc., 440, Fourth Ave., New York 16, N.Y.

CHEMICAL INSTITUTE OF CANADA — "Proceedings of Conference on Nuclear Chemistry." May, 1947.

DIRAC, P. A. M. — "The Principles of Quantum Mechanics." 1947. Oxford University Press, London and New York.

GOODMAN, CLARK AND OTHERS — "Science and Engineering of Nuclear Power." Addison Wesley Press Inc., Cambridge, Mass. 1947.

GOUDSMIT, H. — "Alsos." The German Atom Bomb. Sigma Press, London.

HEIJN, F. A.	"Radioactivity Induced by Neutrons." Meinema N.V., Delft.
HEITLER, W.	"Elementary Wave Mechanics." Oxford University Press. London. 1945.
HEVESEY, G.	"Radioactive Indicators." Interscience Publishers Inc., 215 Fourth Ave., New York 3.
JANOSSY, L.	"Cosmic Rays and Nuclear Physics." Pilot Press Ltd., London.
KAMEN, MARTIN D.	"Radioactive Tracers in Biology." Academic Press Inc., New York. 1947.
LEA, D. E.	"Actions of Radiations on Living Cells." Cambridge University Press, London. 1947.
MATTAUCH AND FLUEGGE	"Nuclear Physics Tables." Interscience Publishers Inc., 215, Fourth Avenue, New York, 3.
MILLIKAN, R. A.	"Electrons, Protons, Photons, Neutrons, and Cosmic Rays." University Press, Chicago.
NATIONAL RESEARCH COUNCIL OF CANADA	"Lists of Declassified Documents." N.R.C., Chalk River, Ont.
NUCLEONICS	"1947 Summary of Nuclear Data." Nucleonics, May, 1948.

PAULI, W. "Meson Theory of Nuclear Forces." Interscience Publishers Inc., 215, Fourth Ave., New York 3.

PHYSICAL SOCIETY, LONDON "International Conference on Fundamental Particles." July, 1947.

POLLARD AND DAVIDSON "Applied Nuclear Physics." John Wiley and Sons, Inc., 440, Fourth Ave., New York 16, N.Y.

POWELL AND OCCIALINI "Nuclear Physics in Photographs." Clarendon Press, Oxford.

ROSENFELD, L. "Nuclear Forces." Interscience Publishers Inc., 215, Fourth Ave., New York 3.

SEABORG, G. T. "Table of Isotopes." Rev. Mod. Phys. *16*, 1 (1944).

SEGRE, E. "Isotope Chart." General Electric Company, Schenectady 5, New York. 1948.

SEREN AND OTHERS "Tables of Activation Cross-sections." Physical Review, 72 (10) 888, November, 1947.

SMYTH, H. D. "A General Account of the Development of Methods of Using Atomic Energy for Military Purposes." Government Printing Office, Washington D.C., and reprinted by H.M. Stationery Office, Kingsway, London.

SUE, PIERRE	"Radioactivité Artificielle." Editions Scientifique S.A., Paris.
THOMSON, SIR GEORGE	"The Atom." Oxford University Press.
UNITED KINGDOM DEPARTMENT OF ATOMIC ENERGY	"Lists of Declassified Documents." D.A.E., Ministry of Supply, Shell Mex House, London, W.C.
UNITED NATIONS ATOMIC ENERGY COMMISSION	"Scientific and Technical Aspects of the Control of Atomic Energy." U.N.O., Lake Success, N.Y. 1946.
UNITED STATES ATOMIC ENERGY COMMISSION	"Lists of Declassified Documents." A.E.C., Technical Information Division, Oak Ridge, Tenn.
WENTZEL, G.	"Quantum Theory of Fields." Interscience Publishers Inc., 215, Fourth Ave., New York 3.
WILSON, D., NIER, A., AND REIMAN, S.	"Preparation and Measurement of Isotopic Tracers." Edwards Publishing Company, Ann Arbor, Michigan. 1946.

Scientific Periodicals

ACTA PHYSICA AUSTRIACA, Springer-Verlag, Wien, Austria.

ANNALES DE CHIMIE, Masson et Cie., 120, Boulevard St. Germain, Paris, France.

ANNALES DE PHYSIQUE, Masson et Cie., 120, Boulevard St. Germain, Paris, France.

ARKIV FOR MATEMATIK ASTRONOMI OCH FYSIK, K.S.V.A., Stockholm, Sweden.

BULLETIN OF THE AMERICAN PHYSICAL SOCIETY, Columbia University, New York, U.S.A.

CANADIAN JOURNAL OF RESEARCH, National Research Council, Ottawa, Canada.

CHEMICAL ABSTRACTS, American Chemical Society, Easton, Pennsylvania, U.S.A.

CHEMICAL REVIEWS, American Chemical Society, Easton, Pennsylvania, U.S.A.

COMPTES RENDUS, HEBDOMADAIRES DES SEANCES DE L'ACADEMIE DES SCIENCE, Academie des Sciences, Paris, France.

COMPTES RENDUS (DOKLADY) DE L'ACADEMIE DES SCIENCES DE L'U.R.S.S., Academie des Sciences, Moscow, U.S.S.R.

HELVETICA PHYSICA ACTA, Basle, Switzerland.

HUNGARICA PHYSICA ACTA, Academie des Sciences, Budapestini, Hungary.

JOURNAL OF THE AMERICAN CHEMICAL SOCIETY, American Chemical Society, Easton, Pennsylvania, U.S.A.

JOURNAL OF CHEMICAL PHYSICS, American Institute of Physics, 57 East 55th Street, New York, U.S.A.

JOURNAL OF CHEMICAL SOCIETY, LONDON, Burlington House, Piccadilly, London, England.

JOURNAL DE CHIMIE PHYSIQUE ET DE PHYSICO-CHIMIE BIOLOGIQUE, Switzerland.

JOURNAL OF PHYSICAL CHEMISTRY (U.S.S.R.), Academie des Sciences, Moscow, U.S.S.R.

JOURNAL DE PHYSIQUE, ET DE RADIUM, Societe Francaise de Physique, Paris, France.

JOURNAL OF PHYSICS, Academie des Sciences, Moscow, U.S.S.R.

JOURNAL OF RESEARCH OF THE NATIONAL BUREAU OF STANDARDS, Bureau of Standards, Washington, D.C., U.S.A.

KONGELIGE DANSKE VIDENSKABERNES SELSKAB, DET, MATEMATISK-FYSISKE MEDDELLSER, K.D.V.S., Copenhagen, Denmark.

NATURE, Macmillan and Co., St. Martin's Street, London, England ; Macmillan Inc., 60, Fifth Avenue, New York, U.S.A.

NATURWISSENSCHAFTEN, Springer-Verlag, Berlin, Germany.

NUOVO CIMENTO, Il Instituto di Fisica, Via Irnero N. 46, Bologna, Italy.

PHILOSOPHICAL MAGAZINE, Taylor and Francis Ltd., Red Lion Court, Fleet Street, London, England.

PHYSICAL REVIEW, American Institute of Physics, Lancaster, Pa., U.S.A.

PHYSICA, Martinus Nijhoff, The Hague, Holland.

PHYSIKALISCHE ZEITSCHRIFT, Verlag von S. Hirzel, Leipzig, Germany.

PROCEEDINGS OF THE ROYAL SOCIETY (LONDON), SERIES A : MATHEMATICAL AND PHYSICAL SCIENCES, Burlington House, Piccadilly, London, England.

REVIEWS OF MODERN PHYSICS, American Institute of Physics, Lancaster, Pa., U.S.A.

SCIENCE, 1515, Massachusetts Avenue, Washington, D.C.. U.S.A.

SCIENCE ABSTRACTS, SECTION A (PHYSICS ABSTRACTS), England.

ZEITSCHRIFT FUR NATURFORSCHUNG, Dieterichsche Verlagsbuchhandlung, Wiesbaden, Germany.

ZEITSCHRIFT FUR PHYSIK, Springer-Verlag, Berlin, Germany.

Supplementary Periodicals

BULLETIN OF ATOMIC SCIENTISTS, 1126, East 59th Street, Chicago 37, U.S.A.

ATOMIC SCIENTISTS' NEWS, 7E, Oxford and Cambridge Mansions, Marylebone Road, London, N.W.1, England.

INFORMATION SERVICE AND SEMI-ANNUAL REPORTS, Atomic Energy Committee, Washington, D.C., U.S.A.

NUCLEONICS, McGraw-Hill, 330, West 42nd Street, New York, 18, U.S.A. ; *and* Bush House, London, W.C.2.

TRACERLOG, Tracerlab Inc., 55, Oliver Street, Boston, 10, Mass., U.S.A.

RESEARCH, Butterworth Scientific Publications Ltd., London, England ; *and* Interscience Publishers, Inc., 215, Fourth Avenue, New York, 3, U.S.A.

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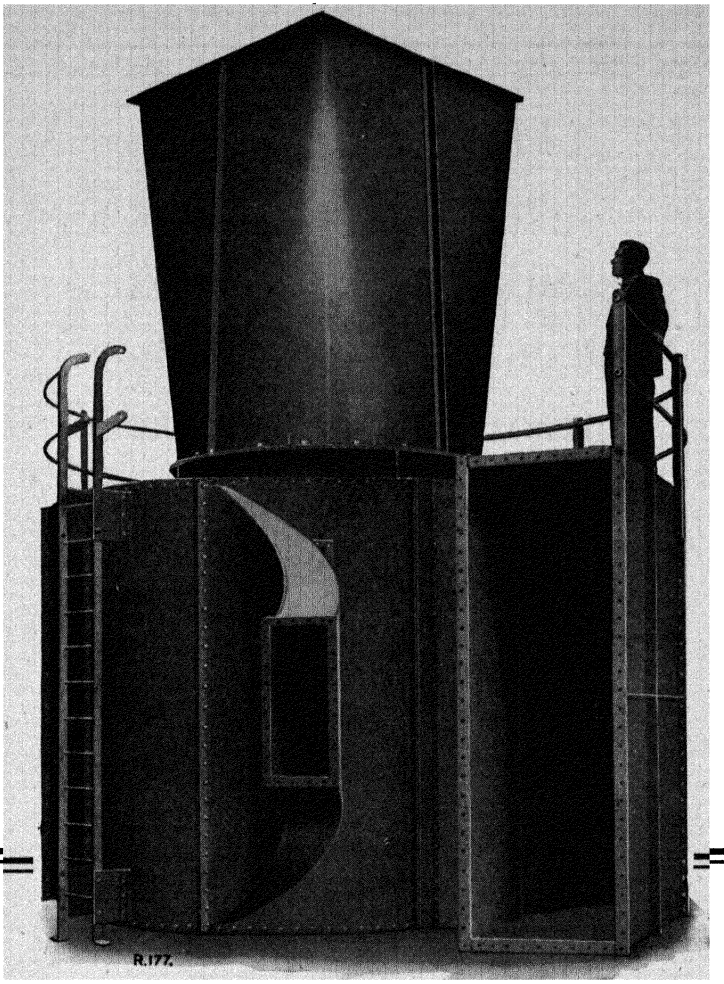

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